# IN-SITU GROUNDWATER TREATMENT USING ARUM

## IRAP/NRC FINAL REPORT 2000

## PROJECT # 28337U

Boojum RESEARCH LIMITED

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## 1.0 INTRODUCTION AND OVERVIEW

In 1995, after 10 years of monitoring the ground water flow from a small Cu/Zn base metal tailings deposit in Northern Ontario, the ground water flow paths were re-evaluated to confirm previously predicted flow directions. A highly contaminated ground water seepage had taken in 1996 a different route and was emerging to the surface contaminating a small lake (Mud Lake). However the seepage path was well defined hydro-geologically and hence it may be suitable for in-situ-treatment. Geo-microbiological in-situ treatment approaches were considered jointly with Dr. Ferris ( University of Toronto). It was proposed, that through microbial urea degradation ground water pH could be increased, resulting in metal precipitation in-situ improving the seepage discharge quality.

A research program was initiated in 1997/98 based on the concept of in situ-increasing the pH through microbial activity which should result in metal precipitation (Schematic 1). This approach needed to be substantiated with microbiological testing and geochemical modelling. This was carried out by Dr. G. D. Ferris at the University of Toronto. Boojum Research Ltd. developed a ground water model for the site to define the quantity of groundwater to be treated and field tested urea degradation.

In May 1999 the theoretical considerations for the in-situ treatment were completed. A report by G. Ferris was submitted to NRC describing the microbiological results from the laboratory tests. The microbial degradation work suggested, that even after cell death the released urease enzyme continues to lyse urea. The geochemical modelling completed as an MSc thesis indicated, the byproducts of microbial activity could suffice to increase the pH to about 8. Such pH increases could be expected with urea concentrations in the mM range. These results were encouraging and increased the probability of metal precipitation in-situ.

Although these results were encouraging, the most complex area of implementation is encountered in the field of aquifer systems in porous media, a complex field of fluid flow (Gilbert et al. 1994 Ground water ecology). This area does of ground water flow does not become simpler when the definition of the microbial urea degradation rates are addressed in the field. The authors Amy P. S and Haldeman D. L. (1997) in: ' The microbiology of the Terrestrial Deep Subsurface' make it clear, that microbial activity in these porous media is exceedingly complex.

Albeit the complexity, a field test area was selected. A clay bowl filled with sand /till to a depth of about 1 m was located, where seepage from the adjacent tailings flows through ( or is suspected to flow through) to a deeper bedrock valley ( Kalin Canyon), finally emerging in Mud lake the deeper bedrock. This "Sandpit" was instrumented with shallow piezometers and a urea plume was created. Monitoring of the urea degradation, along with collecting water samples and measuring water level over a period of 3 years was expected to produce the needed application rate of the nutrients ( urea and carbon) for the desired pH increase.

However the flow in the shallow 'aquifer in porous medium' does display all the anticipated complexities, particularly within the restraints of obtaining field data within a reasonable budget from a remote site. We could not define the application rate by end of 2000, the end of the target date for the NRC support of the project. However the project is continuing.

After 3 years of monitoring the urea plume has decreased dramatically. An initial concentration of 2140 to mg/L of TKN ( 1 mg/l of TKN is 2.14 mg/L urea) in June1999 to 79 mg/L in September 2000 in piezometer MSP11. A second piezometer ( MSP13) showed a similar decrease in TKN. The acidity decreased in piezometer MSP11 from an initial 6378 mg/L of $CaCO_3$ equivalent in 1997 after the urea application and carbon supply to the microbes to as low as 1944 mg/L$CaCO_3$ equivalent in 1999, but fluctuated back up to 3181 mg/L by September 2000. Although piezometer MSP13 showed equally impressive reductions of acidity, from 17,825 mg/L $CaCO_3$ to as low as 5735 mg/L $CaCO_3$ in 1999 but also fluctuated by 50 % back to its original acidity. Although this could represent the new influx, it is not easy to determine, as the Sandpit is an unconfined aquifer with no boundaries. Therefore the attribution of the water quality improvements to the microbial activity was not possible, although it was suggested. Twenty three ( 23) additional piezometers , very closely spaced in a circle were installed by October 2000, in the centre of which a new plume was created.

An installation for urea application to treat the underground seepage contaminating Mud Lake is in place on the shores of Mud Lake, awaiting injection of urea in spring 2001, when the results of the second urea plume degradation are at hand. Although the ultimate objective of the research program was not yet achieved ( defined in the proposal by an improvement of metal loading to Mud Lake) we are confident it will be possible after completion of the second degradation experiment by spring 2001.

In this report, the background is provided for the final scale up on the shores of Mud Lake. In Section 2 the ground water flow regime of the entire drainage basin is defined using Visual Modflow. A complete flow budget has been developed, to define shallow and deep ground water flow volumes. Of great concern were any potential other seepage paths away from the tailings. Those could either also be treated by the generation of in-situ barriers, due to precipitation of metals. On the other hand, the change in hydraulic conductivity and porosity due to the precipitation, also requires a good understanding of the ground water flow regime, such that the effects of the in-situ treatment can be predicted.

In Section 3 of this report , the real time measurements in the drainage basin are used to verify the model results. The evaluation of the response of the water level in the drainage basin (mainly tailings) to increases in water level in Mud Lake ( beaver activity) allows verification of the model. The findings are that the modelled and the measured results agree. In section 4 the installation for the urea/carbon in-situ treatment is described in detail and background conditions are being monitored. The model is used to simulate ( with injection wells) the effects on the ground water flow regime, with the proposed treatment arrangements.

In Section 5 the work on urea degradation is described, concluding with the rational used for the set up of the second urea plume installation.

## 2.0 GROUND WATER FLOW MODEL OF THE DRAINAGE BASIN

During 1997 and 1998, extensive modelling of the tailings basin and surrounding area was carried out using Visual Modflow, a program developed by Waterloo Hydro geologic. This three-dimensional groundwater flow model has become an industry standard and has been subject to extensive verification and validation studies. It is used by many consulting firms as well as by USGS and USEPA.

Visual Modflow was used first to construct a regional model describing the entire South Bay mining site basin. Once this model was calibrated to provide reasonable agreement with measured water levels in the extensive array of monitoring wells and the measured flow regime, the results were used to construct a model of the tailings basin, including Mud Lake, Boomerang Lake and the Town Site. An overview of all relevant areas of the South bay site is given in Map 1.

The Tailings Area model was also calibrated to provide agreement with measured water levels and surface flow estimates, using atmospheric precipitation, infiltration and run-off estimates. The results of this modelling were reported as part of the interim report submitted to NRC previously (A Modelling Study of the South Bay Mine Site, SCIMUS Inc., March, 1998). The initial model development was based on a 200x 200 ft grid covering the drainage basin with the tailings, assuming 5 equally spaced layers between bedrock and the surface elevation, defined by SURFER.

Although this produced satisfactory results for the overall drainage basin, flow balance problems were encountered with convergence of the cells when the model was used specifically for the tailings area, estimating the effects of changes in water levels and alterations to the tailings surface. Refinements were needed, consisting of decreasing the grid size to 50 x 50 ft and construction of a detailed 6 layer model using detailed stratigraphy for all location available (114 piezometer drill logs). These refinements to the model allow a more detailed investigation of flows across the modelled regime. No further problems with convergence were encountered.

In order to reduce the groundwater seepage flow, not only its treatment has to be considered, but its reduction at source. Therefore an investigation of the effect of raising and lowering the Decant Pond was part of the use of the model. From the hydro-geological assessment of the water levels in the drainage basin along with the geochemical investigations of tailings pore water evolution and contaminant generation, the fluctuating water level in the tailings was undesirable. The model indicated that with the lowest possible water level in Decant Pond, the water level alterations in the vadose zone are reduced such, that they remain mainly below the tailings mass. This would leave only atmospheric precipitation to be the main contributor to contaminant generation. The model showed that most of the water is moving in layer 2 and 3, below the tailings mass (Table 1).

Using the model we estimated the expected reduction of the seepage to Mud Lake if atmospheric precipitation could be converted from infiltration to run-off for the tailings area. Such a scenario, although difficult to implement, produced estimates that a reduction of the seepage flow to Mud Lake up to 40 % could be achieved, if infiltration was reduced by 100 %.

The next step was therefore to define the area in the tailings where most of the infiltration took place from the spring and fall. This would be the area of the most obvious place to start implementing a self sealing cover with phosphate to reduce infiltration. This area has been identified as the Tailings Run-Off area (TRO). Water is accumulating throughout the year in a hourglass shaped small pond. Confirmation could be obtained from the model. Equipotentials ( direction of flow ) suggest infiltration to the first layer of ground water in this

area clearly.

Phosphate applications have been implemented, in 1998 on an experimental basis and full scale by the fall 2000. 21 tonnes of phosphate have been placed in the Run-Off area, as indicated in Schematic 2. Application rate based on approximate area is **XXXX** Details of this work are not reported further in this report. The application of phosphate is based on Boojum's work on inhibition and reduction of acid generation with phosphate ( Kalin,1998, Kalin et. al. 1995).

For the seepage treatment to be effective in the overall restoration of the South Bay site a comprehensive understanding of the ground water seepage pathways is required. At the onset of the project, it appeared that most of the seepage passes through a bedrock canyon below the gravel pit, named by the hydro-geologist of the project 'Kalin Canyon.' A complete accounting of the groundwater mass balance is needed , such that the location of the in-situ treatment will be most effective in reducing the contaminant load to surface water. Thus all alternate ground water seepage pathways have to be defined, prior to selecting the scale up location. In the following section considerations of alternate flow paths of ground water seepage from the tailings deposit are described.

### 2.1 Potential alternate flow paths South of tailings - town site

In 1990, two years after the start up of the project a hydro-geological model was build for the contaminant plumes from the tailings site. In Schematic 3 the ground water flow directions projected per annum are given. As the plume moving south of the tailings towards the town site was considered undesirably close to Confederation Lake, a Ground Water Diversion ditch was constructed to a depth of about 3 to 4 m below the shallow tailings layer. Although the ditch reports a small amount of seepage the deeper ground water flow regime was unclear using the interpretation of the hydro-geology form the town site area.

This area had undergone construction producing a extremely heterogenous stratigraphy. Increases in the number of piezometers in this area was unlikely to improve the probability of prediction on ground water flow. Investigations of aerial photograph of the topography prior to tailings deposition indicated a depression, on the south eastern corner of the tailings pond (Schematic 4). This potential pathway of the seepage and the effectiveness of the Ground

Water Diversion ditch constructed in 1991 to the south of the Tailings Area could be addressed with the model.

In order to more accurately simulate the flow in this region, the hydraulic conductivities of the various layers in the region of the diversion ditch and the former townsite were refined based on a data collection made over the past decade. These are shown in Figures 1 to 4. The colour scale used in the figures is defined in Table 2.

The resultant equipotentials in each modelled layer in the area to the south of the tailings are shown in Figures 5 to 8. The regions in yellow represent dry cells. Figure 9 shows the locations of the monitoring wells used to compare measured versus observed heads. The results are shown in Figure 10 and Table 3. It can be seen that apart from monitoring wells M22 and M42, agreement is within about 1 m. The water levels in both M22 and M42 are anomalously high due to very localized conditions ( construction of the ditch and damage to M22 piezometer). They are considered not to influence the flow regime at large.

With the refined flow regime for this area the effectiveness of the ditch was evaluated, using the model to simulate transport of contaminants from the tailings with the contaminant transport portion of Visual MODFLOW. As piezometer installations on the other side of the ditch are reaching to depth of 24 (M78A) and 19 (M42) meters, the water quality in the piezometer may confirm or refute the contaminant transport model results.

The transport of contaminants used zinc as a conservative contaminant. Concentrations of zinc in the various piezometers that are screened in the tailings were reviewed in order to develop a source term for the model. From the results of the field measurements between 1986 to the present, it was determined that the zinc concentration in the tailings was best represented by a constant value of 700 mg/L. The source is shown in Figures 11 and 12. No retardation and a longitudinal dispersion of 10 ft were assumed. Twenty years of transport were simulated.

The concentrations contours at 100 mg/L intervals are shown for each of the layers at 5, 10, 15, and 20 years in Figures 13 to 28. The value of 150 mg/L would be predicted from the isopath generated from the transport modelling for piezometer M78A and 20 mg/L for piezometer M42. The measured concentrations in location M78A were 198 mg/L in 1995, 170 mg/L in 1996 and 150 mg/L in 2000. In location M42 0.11 mg/L in 1986, 16 mg/L in 1996 and 19 mg/L in 2000. These concentrations are in excellent agreement with the projection from the transport modelling.

It can be concluded that any zinc in the upper two layers is completely intercepted by the diversion ditch. In the lower two layers there is some movement beyond the ditch. The effectiveness of the ditch in containing the contaminants from the tailings is shown in greater detail in Figures 29 to 32. These show the velocity vectors representing the groundwater flow magnitude and direction for each of the modelled layers as well as the leading edge (from 100 mg/L to 10 mg/L) of the contaminant plume. The contaminant in layers 1 and 2 is almost completely contained by the ditch, except for the southwest corner in layer 2. As seen from the velocity vectors in Figure 30, most of the flow in this corner will eventually return to the ditch.

In layer 3 as seen in Figure 31, there is a component of the flow to the south from the south-eastern corner of the tailings into the town site however, further progress is likely to be insignificant since the velocities are very small in this region (shown as a white out area). There is some movement to the west towards Confederation Lake, however, since the velocities in this direction are very small, the contaminant plume is likely to be diluted to background levels before reaching the lake.

In Figure 32 showing flow and contaminant transport in layer 4, it is seen, as in layer 3, that there is evidence of contaminant movement to the south and to the west from the southeast corner of the tailings. Most of the southward moving contamination will likely return to the ditch based on the direction of the velocity vectors. As in the case of layer3, because the velocities are gradually decreasing in the direction of travel to the west, it is unlikely any contamination will reach Confederation Lake in above background concentrations.

From the above modelling exercise, it appears that the results indicate that the diversion ditch is effective in containing the contaminant plume from the tailings areas in all depths of the overburden.

Based on these evaluations the location of the in-situ treatment area clearly restricts itself to the area of the 'Kalin Canyon' and its discharge areas in Mud Lake. These areas will be discussed in detail in the section below.

### 2.2 Ground water flow in the tailings deposit and seepage pathway

The boundaries between the four layers of the tailings were better defined as described previously in order to avoid overlap between layers and thus obtain convergent solutions during the flow modelling. The various flow zones described in the previous modelling study (Modelling Study of South Bay Tailings Area (Phase 2), SCIMUS Inc., July, 1999) were maintained, but it was now possible to allow estimates to be derived for the flow contribution of each modelled layer. With this information, the in-situ treatment location can be identified and quantities of water to be treated can be estimated for each layer. In addition it facilitates the quantification of the groundwater flow along the major contaminant transport paths. The refined zones are shown by layer in Figures 33 to 36 and a description is given in Table 4. The various flows are presented in Tables 5 to 14. The units are $m^3/a$. Although all flow zones are included for completeness of the assessment, detailed discussion is only given for region which are of immediate interest to the ground water seepage paths to be treated in the future.

**Tailings** : From Table 6, it can be seen that the major flow from the tailings is vertically downward into the lower layers (Zones 2 and 22 to Zone 13). In Table 7, it can be seen that in layer 2, about 23,000 $m^3/a$ of water flow from the tailings (Zones 2 and 22) into the area directly beneath it (Zone 13). This is about 85% of the flow in this region and thus the contaminated tailings water is only slightly diluted. In layer 3, the flow from the layer directly above in this same region (Zone 13) is about 18,600 $m^3$/a or about 60% of the total flow. Thus, there is more dilution of the contaminated water beneath the tailings in layer 3. In layer four, there is further dilution, as again only about 65% of the water originates from the layer directly above in the tailings region (Zone 24).

**Kalin Canyon** : In Table 8, it can be seen that the flow into Kalin Canyon from the Tailings Area originates mainly from layers 3 and 4 (391 $m^3$/a, layer 1; 3485 $m^3$/a, layer 2; 5507 $m^3$/a, layer 3; and 11,173 $m^3$/a, layer 4). The rest of the flow from the Tailings Area is south and east to the diversion ditch and Boomerang Lake (Zones 18, 29, 39; about 17,000 $m^3$/a) and north towards Mud Lake (Zones 20, 31, 41; about 7,000 $m^3$/a) (Table 7).

**Mud Lake**: Table 9 shows the various contributions to Mud Lake. Inputs from layers 1 and 2 contain largely water from uncontaminated regions. Kalin Canyon (Zone 26) is the largest contributor of contaminated water to Mud Lake in layer 3 (11,357 $m^3$/a). Only 646 $m^3$/a originate from Zone 31, another contaminated pathway. In layer 4, again Kalin Canyon (Zone 36) is the main contributor at 12,835 $m^3$/a; however, the contribution from Zone 41, the other contaminated pathway is larger, 3,399 $m^3$/a. In the Mud Lake water balance, there appears to be an imbalance of just over 1000 $m^3$/a in each layer. This probably results from errors in the designation of the river nodes to simulate Mud Lake. This imbalance does not affect the conclusions reached in this investigation.

## 3.0 VERIFICATION OF MODELLED CONDITIONS

Although the imbalance of flow is not expected to produce leakage of highly contaminated water in unpredictable locations, it was considered prudent to evaluate the entire model by using the overall drainage basin to verify the reliability of the model as a tool. This opportunity arose, as beaver activity increased in Mud Lake area, increasing the water level of Mud Lake over the 1998/1999 season gradually by about 0.5. At the same time, water level measurement intensity was increased in the tailings area, to provide real data on the effect of the water level raise on the ground water regime, relevant to this study.

Mud Lake was modelled 0.5 m and 1.0 m higher elevation in order to simulate the effects of a beaver dam on the flows from Kalin Canyon. At 0.5 m increase flows to Mud Lake decreased to about 73 % of the flow above from Kalin Canyon (Zones 26 and 36) and about 83% of the flow from Zones 31 and 41 (North of Tailings to Mud Lake). At an increase of 1.0 m, the flows decreased even further to 38 % for Kalin Canyon (Zones 26 and 36) and 0.67 for Zones 31 and 41. After raising the water level, according to the model, the direction of water flow between Mud Lake and West of Kalin Canyon was reversed for layers 2, 3 and 4. The zones 11, 21, 32 and 42 (East of Mud Lake - North of Decant Pond) show very little changes compared to the other zones. The effect of changes in water level on the ground water flow regime are presented in Schematic 5 to 7. The arrows present direction of ground water flow and the numbers indicate water flow volume in $m^3$/year.

It was clear, that Mud Lake at lower or it's normal elevation without a beaver dam at the outflow is a was desirable elevation. The beaver dam was breached to lower Mud lake and the remaining dam was equipped with a pipe. It is hoped that the pipe is installed in such a fashion, that beaver activity is prevented.

Although the model results seem to suggest, that all ground water seepage can be directed towards a discharge in Mud Lake, if the original water level is maintained, confidence in the model can be increased with verification. Measurements of water level in the affected area, as predicted by the model would confirm or refute the understanding gained through the model about ground water flow. Verification of the surface water volume leaving Mud Lake with the overall flows of the drainage basin has been obtained, along with a mass balance of elemental cycling in Mud lake. A good agreement was found between groundwater discharge to Mud lake, the expected outflow volume and the measured outflow of surface water. The lake turns over three times a year and the contaminants from the ground water seepage stratify along the sediment surface. These results are not presented here.

The water level data collected during the higher Mud Lake surface water elevation, where used by the hydro geologist of the project, to assess the effects on the ground water regime. The evaluation is presented below. It should be noted that Dr.A. Vonhof did not know the modelling results when her assessed the data. The model is run by W. Polizot.

## 3.1 Mud Lake Water Level Rise (Dr. A. Vonhof)

During late Summer/early Fall 1999 a number of industrious vagabond beavers built dams across the outflow of Mud Lake. This resulted in a rise in the water level of Mud Lake (ML) of approximately 0.6 m.

The question therefore arose: What is the effect of this ML water level rise on the hydrodynamic environment ? In other words: what is the effect on the subsurface inflow from the Tailings Basin (TB) to Mud Lake and the possible increased subsurface outflow from Mud Lake in a northeasterly direction.

### 3.1.1 Background

Previous work has shown that ML is a groundwater discharge area for the Kalin Canyon. This buried valley is the main conduit for the transport of contaminated groundwater from TB to ML. The occurrence of the groundwater discharge from this buried valley indicates a significant change in the lateral transmissivity of the valley fill, which can have a number of causes. These are:

- The northern end of ML is the start of Kalin Canyon in bedrock.
- A very significant change in the type of buried valley fill (from very high to low permeable sediment).
- A very significant reduction in the thickness of the permeable sediment.
- A combination of the above points.

No subsurface data exists for this part of the basin, other than surface resistivity surveys, and the exact cause is therefore not known.

### 3.1.2 Effect of Mud Lake Water Level Rise on Subsurface Inflow

A: Water Levels

The effect of the water level rise in ML on the hydrodynamic environment of the basin was evaluated by plotting the elevation of the water level of a series of piezometers both inside and outside the TB versus time. The results are shown in Figures 37, 38 and 39. (NOTE: the overall scale of the Y axis is the same). Only the water level in March was considered.

The overall trend from 1987-2000 shows gently rising and falling water levels. A relative sharp increase in the water levels can be noted from 1999-2000. The elevation of the water level in all piezometers is the highest in 2000, except for M31 & M33 (Figures 37, 38 & 39). These latter two piezometers show over the period 1987-2000, for a number of years, elevations of the water level which are considerably higher than in 2000 (Figure 38).

If the long term trend is considered the piezometers completed in the northeastern part of the TB show the greatest relative increase in the elevation of the water level over the period 1987-2000 (Fig. 38). A significant increase occurred from 1993 onward, which, as pointed out in a previous report, was caused by an increase in the elevation of the water level in Decant Pond.

Piezometers M50 and M54 show the least amount of variation of the elevation of the water level over the period 1987-2000 (Figure 39). M54 is a shallow piezometer completed on the shore of Confederation Lake. The elevation of the water level in this piezometer reflects primarily the changes in the elevation of the water level of Confederation Lake. The long-term trend shows a slight rise. M50 is a deep piezometer located in the old town site. No other deep piezometers are present between M50 and the shoreline of Confederation Lake. It is, however, suspected that groundwater flows from M50 toward the lake. Consequently, the elevation of the water level in the lake will exert a strong influence on the water level in M50. This is obvious from Figure 39, which shows a considerable parallelism in the plots of the elevation of the water levels of M50 and M54. March 2000, however, shows a slightly greater increase in the elevation of the water level of M50 as compared to M54 and the trend in previous years.

In conclusion, it is obvious, that changes in one part of the environment, i.e. the rise in the water level of Mud Lake, affect the total hydrodynamic environment to various degrees.

The frequency of water level measurements was drastically reduced a number of years ago, because long term trend analysis had shown relatively predictable pattern. However, the reduction in the frequency had not counted on the activity of a number of beavers who decided to settle in the northern end of ML. As a result the data base is somewhat meagre to follow the effect of the building activity of the beavers. Fortunately, there is some data available over the period from March-May, which also include the Spring melt recharge event. This is illustrated in Figure 40. As can be seen in this figure, the elevation of the water level in the piezometers has been dropping steadily from 1996-1999. However, a sudden and significant change occurred from 1999-2000 over the time interval from March-May.

B. Gradients

The change in the water level of ML during 1999-2000 has significantly affected the hydraulic head distribution as shown above. The hydraulic head distribution, in turn, determines the gradient along a specific flow path. If no changes occur in the transmissivity and the cross-sectional area along the flow path, then the rate of groundwater flow is determined by the gradient and its changes with time.

The changes in the gradient from February-May over the period 1996-2000 is only illustrated for a small number of piezometers. Figure 41 shows the changes in gradient between M69, M72A & M83A and M79. This figure shows that the gradient can vary considerably over the period from February-May within one year and between years.

Although data for specific dates (Feb.-May) for each year over the period 1996-2000 is not consistently available, Figure 41 illustrates that the gradient displays a considerable range for each of the years in the period 1996-1998, but becomes much more muted for the period 1999-2000.

This becomes very evident if only the gradients in March and May are considered (Figure 42). This figure illustrates that the gradients in March are more or less the same over the period from 1996-2000, but differ considerably from those in May. The May gradients show a significant increase from 1996-1998, but a much smaller increase from 1999-2000. The much lower values of the "May" gradient in 1999 may be due to the date of the measurement (April 21), which, therefore, may not reflect the total effect of the Spring melt

in that year.

It is unfortunate, that no information is available on the water level in ML over the period from 1996-2000, because of the effect this water level has on the hydraulic head distribution. Another factor which strongly influences the hydraulic head distribution is the annual Spring melt and subsequent recharge. This will be discussed in more detail below.

### 3.1.3 Spring Melt

The annual Spring melt is the main and most important groundwater recharge event. To determine the relationship between the precipitation and the elevation of the groundwater in March a number of steps have to be undertaken.

A: Relationship between water levels in piezometers in October and March in the following year.

Figures 43 and 44 show the elevation of the water level in October and March of the following year in 2 sets of piezometers within the TB. The October value was used to represent the elevation of the groundwater after no further recharge would occur, because of the onset of Winter. The March value shows the elevation of the groundwater prior to the Spring recharge event and the March data has been used extensively above. Both figures show that the magnitude of the elevation of the water level in March is consistently lower than in October of the previous year. Furthermore, where sequential data is available, it shows clearly that the trend from year to year in October is reflected in the corresponding March data for the following year.

B: Precipitation Data.

Figure 45 shows the precipitation data for the period 1991-1999. Three different traces are shown. The total winter precipitation represents the interval from October 1 to March 31 of the following year. The total summer precipitation represents the interval from April 1- September 30 in the same year and the total precipitation is the sum of the winter and summer precipitation and covers the period from October 1 to September 30 of the following year. The winter precipitation is plotted on March 31 and the summer and total precipitation are plotted on September 30 of the same year. It is obvious that the bulk of the precipitation falls during the summer, but previous analysis of summer precipitation versus a rise in the groundwater level has shown, that only major storm events are reflected by an increase in the elevation of the groundwater level.

C: Relationship between precipitation and elevation of groundwater.

Figure 46 shows the elevation of the water level in a number of piezometers superimposed on the precipitation data. This figure clearly shows that the trend in the magnitude of the winter precipitation, i.e. the amount of water available during Spring melt, is beyond doubt reflected in the trend of the elevation of the water level in the piezometers in October of the same year, except in 1999. The correlation between the winter precipitation and the elevation of the water levels is much better than the total precipitation.

The significant rise in the elevation of the water level in October 1999, cannot be accounted for by the precipitation data. Based on the trend of the precipitation data the water level in October 1999 should have been lower than in 1998. In other words, the observed rise in the elevation of the water level in October 1999 is solely due to the handiwork of the beavers in the outflow area of ML, which resulted in a rise in the elevation of the water level of ML.

As was pointed out above, there is a good correlation between the water level data in October and March of the following year. The significant rise in the water levels of the piezometers in March as shown in Figures 37 and 38 is entirely due to an increase in the elevation of the water level of Mud Lake.

If the elevated water level of ML was allowed to be maintained by the beavers, a new equilibrium would be established in the future and trends between precipitation and water levels would also be re-established. Under these conditions the overall elevation of the water level within the TB would rise.

Destruction of the beaver dam(s) will drop the water level in ML relatively rapid. As a result a disequilibrium will be created between the TB and ML, which, in turn, will result in a slug of contaminated water moving along Kalin Canyon towards ML due to an overall lowering of the water level in the TB.

### 3.1.4 Effect of Mud Lake Water Level Rise on Subsurface Outflow

Just as the rise in the water level of ML affects the inflow into the lake, it will also increase the subsurface outflow from the lake due to the increase in hydraulic head caused by the increase in the elevation of the water level. If permeable continuous sediments are present in the subsurface under the northern part of ML and continue in a northeasterly direction than the rate of movement of contaminated water will also have increased.

Unfortunately, there is no stratigraphic information available in this area, because drilling in this area is impossible, due to the floating muskeg. The only information which is available, is the result of a surface resistivity survey. To determine if any movement of contaminants has occurred, it is suggested that additional resistivity surveys are conducted along the same lines as previously as a monitoring tool. As such surveys can only be carried out during the winter and are time consuming, the northern lakes ( Armanda and Lena lake, Map1) are sampled once a year. As the elemental mass balance produced very satisfactory results, we do not anticipate escape of contamination through the ground water, as water does take the easiest path of resistance.

It can therefore be concluded, that the model reflects the behaviour of the drainage basin and the ground water seepage path is well defined. In the next section, the selection of the treatment location and its instrumentation is reported.

## 4.0 HYDROLOGICAL SCENARIO FOR IN SITU -TREATMENT APPROACH

The urea degradation work which had progressed slowly in the laboratory and the field. A brief overview is given in the following sections. It was indicated based on the work by G.

Ferris ( U of Toronto) that carbon may be a limiting factor in the degradation of urea. In addition the high metal values in the seepage may be inhibitory to microbial activity, although microbes were present as confirmed by the sRNA analysis ( Kalin et al 1998). The in-situ treatment approach was therefore expanded to generating a high pH environment in a uncontaminated setting, rather than attempting to generate the higher pH within the plume.

This was particularly suggested by the physics of the contaminated plume. The contaminant plume produces a denser liquid than the fresh water which enters the ground water from infiltration, and mixing of the high pH water with the plume is therefore unlikely.

Although it is generally believed that diffusion would facilitate mixing of the two solution, more detailed assessments of the reality indicates, that diffusion is certainly slower than the movement of the plume. Forces separating denser solutions are stronger than those mixing them. This has major implication for in-situ treatment of metal contaminated seepages, as it will be close to impossible to produce a urea plume, with microbial activity

at a density necessary to mix with the seepage.

Instead however, it will be feasible to generate alkalinity and increase the pH in a ground water stratum to lead to precipitation of the metals as the plume encounters the high pH region. If the treatment location is selected such, that the alkalinity generating plume will advance prior to the plume, where it will precipitate, then it may be possible to realize the overall objective in reducing the contaminant load to Mud Lake.

Of course the envisaged scenario can be immediately dismissed as pessimists will suggest correctly that with the precipitation of the metals, the porosity and hydraulic conductivity will be changed and hence the seepage will take a different paths. This would be equivalent to treatment by injection of alkaline solution in a piezometer or by an injection well. However it can be argued, that if the correct location for in-situ treatment is selected, then the irritating behaviour of water flow, taking with guarantee the easiest paths of resistance, could once be exploited. It is expected that the plume will path around the area where the metal precipitated, forming an in-situ barrier.

If the in-situ treatment area is located in a relatively homogenous layer, where the pH increased plume would precede the metal increased plume the approach may succeed. Although these assumptions remain assumptions until tested, these were the guiding hydrological criteria for the site selection. In brainstorming session with the project team we searched for a treatment area with homogenous material which was naturally reach in carbon, not contaminated and where deep contaminated seepage flow could be directed passively to an area were pH could be increased.

Martin P. Smith identified the shores of Mud Lake. Here a layer of about 4 m of gytta (loonshit) exists surrounding Mud Lake and several piezometers are located around at different depth, M60A at 16 m and M60B at 8 m. The piezometers indicate, that a positive pressure exists between the deeper layers and the surface layer, which would lead to

release of the deep contaminated seepage. This flow could be redirected to the 4 m deep gytta of layer 2 (zone 20, Table 13 shows little flow in this layer). If instrumented accordingly the shallower stratum provides a homogenous carbon rich environment, where urea degradation could increase the pH. The resultant instrumentation is given in Schematic 8.

## 4.1 Mud Lake of installation on shore

- An 82.5' long PVC pipeline was installed in a trench through the muskeg from M60A inshore such that the line is at or below the Mud Lake water level.

- The line was connected to M60A using a “Tee” installed at the base of the piezometer. A plastic ball valve was installed between M60A and the pipeline to the injection system.

- Six injection wells were pushed into the muskeg. The first injection well was installed in early June, 2000. This well is comprised of a 5' riser with a 5' screen, i.e. the tip is approximately 10' below ground and solutions are injected into the 5' to 10' muskeg stratum. The other five well are comprised of 10' of screen with a 5' riser, such that solutions are injected into the 5' to 15' stratum. The wells are 20 ‘ apart, referred to as I-1 to I- 6.

- The screens of the injection wells were not pushed down to clay, since the roughened re-bar probe tests indicate that clay is more than 20' below surface in the injection area while clay was found at 18' beside M60A. Moreover, it appears that the coarse, fibrous, partially-decomposed muskeg in the top 10' has a much higher hydraulic conductivity and will readily accept injected water, while the fine, yoghurt-like gytta‘s hydraulic conductivity is very low.

- The six injection wells were plumed into the line from M60A using PVC “Tee” connections and glued. The entire injection system was assembled suspended about 0.2 m above the Mud L. water level. Following assembly, the wells and connector piping were evenly bumped down such that the entire water distribution system lies under water and sits level. Surveying equipment was used to verify even levels.

- An array of ten (10) monitoring wells (TN-1 through TN-10: “TN” refers to “TeN feet deep”) were installed 30' from their nearest injection well (see Schematic 8). The piezometers consist of one 5' section of screen an on 5' section of riser pushed down to ground level. Therefore, water bailed from these piezometers are samples from the 5' to 10' stratum. A second 5' riser was attached as the stick-up portion of these “TN” piezometers.

- A further array of six (6) deeper monitoring wells (FT-3 though FT-8 “FT” refers to “FifTeen feet deep”) were installed adjacent to and one m from TN-3 through TN-8.

These monitoring wells screens will sample muskeg pore water between 10' and 15' down. A third 5' riser was attached as the stick-up portion of these “FT” wells.

- Up to eight litres of water were bailed from all wells. Water samples were collected and the general chemistry (pH, temperature, conductivity and redox) of samples determined immediately in the field. Samples of TN-3 and TN-13 were kept for filtration and chemical analysis (Table 16b). In comparison to the water to be treated ( 60A ) the monitoring wells are clean, as expected from the results of 60 B. The elevations of all injector wells were surveyed with respect to the M60-A and M60-B piezometers previously surveyed.

- A section of the pipeline from M60-A to the injector wells has been equipped with two threaded junctions 21" apart for installation o the flow meter.

- The rate at which the well system accepts water was determined (0.3 $L.s^{-1}$) using a 1 $m^3$ tank and fire hose draining to the injection system at a flow rate which maintained injector well water levels at the same head as when M60A head was applied (Table 15).

The wells were all bailed (up to 8 L each) and field chemistry was determined for the muskeg pore water in the vicinity (Table 16a). The pH values range between 5.1 and 6.5 have low conductivities and a relatively low Eh. Table 16b presents the assayer results for collected samples (TN-3, TN-13) and the piezometers M60A, M60B, middle Mud Lake (MML) and Mud Lake outflow (ML18) for comparison. Elevations of the injection and monitoring wells were surveyed (Table 17).The system is presently switched off, and will not be operated pending approval from the regulatory agencies.

The system will be operated as follows:

- dissolved urea and/or other compound will passively injected in first period

- AMD via M60A injected in second period.
- plume will be followed by periodic bailing then sampling of monitoring wells.

In order to predict the effects of this site location and its flow regime in the vicinity of Mud Lake, an injection well, injecting water at the rate of 1 L/s was simulated in the model. The first simulation assumes that the injection is made to layer 2 through one injection well. Schematic 9 presents the flows for this simulation. Second simulation assumes that the injection was split among 3 injection wells and the flows for this simulation are presented in Schematic 10. The flows through Kalin Canyon are the only flows affected by this wells. The flow in layer 2 is increased by 70% and the flows in lower layers (3 and 4) are decreased by 10% and 15% respectively.

## 5.0 UREA DEGRADATION

The most difficult task is the assessment of the fate of urea in the sand pit along with the anticipated increase in pH and decrease in metal acidity. A better understanding was gained as time progressed and the data set increased. Although water samples were collected and preserved ( filtered 0.45 um and acidified) for later determination of elemental composition, the hydrological conditions needed to be clarified first. Between the dynamic nature of the water flow within the sandpit and the diffuse source of contamination entering the sandpit from the adjacent tailings, it was difficult to determine if the proposed processes are contributing to the water quality changes.

Values of pH, Eh, metal acidity and electrical conductivity were used as overall monitors of the water quality. In the first year of the experiment, it appeared that acidity decreased as indicated in the introduction, but the increasing data set also increased complexity.

### 5.1 Urea Plume Estimates

On September 21, 1997 a total of 350 kg of urea was placed in 14 holes in the Sand Pit. According to water elevations urea was expected in the piezometers MSP4, MSP9, MSP6 (later because of distance), MSP11, MSP5, MSP13, MSP12 and M72C. July 1999 sampling proves that urea is present only in MSP11 and MSP13 (mainly), and a very low concentration in MSP12, MSP10, MSP9, MSP5, MSP1. This observation allows us to verify the calculation of urea concentration. A trapezoid between urea hole UA1, shallow piezometer M72C and urea hole UB14 was taken as the main area containing urea. This area is about 116 $m^2$, and converts to 23 $m^3$ of water.

Map 3 gives the trapezoid layout and the TKN values determined on the September 1999. The urea concentration (without any dilution) is about 15000 mg/L, which converts to 7000 mg/L of TKN. The total precipitation for the period from urea placement to sampling time in July 1999 is 1260 mm. About 1/3 of this is net precipitation (420 mm). This gives about 49 $m^3$ of water on this area during the period of urea placement till last sampling. Taking this dilution into account the urea concentration is 4850 mg/L, equivalent of 2250 mg/L of TKN.

From the hydraulic heads a velocity of about 2 cm/day was projected with a general direction of the ground water away from the application area MSU-A toward MSP9.
Thus the urea plume would have been expected to arrive at piezometer MPS9 (Map 2b) around spring 1999. In May 1999 about two years after the application of urea the value was 2140 and 2130 mg/L of TKN in MSP-11- and MSP 13 respectively. As all the water samples were stored ready for chemical analysis, the sample from August l998 was submitted for analysis and a lower concentration of 334 mg/L and 513 mg/L of TKN reported for MSP-11 and MSP-13 respectively (**Table a to c)**. From the chemical analysis of these waters, once the plume was identified, it does suggest a reduction in acidity over the time span where measurements exists, if this was due to the additions made . By the end of the year 2000, we are certain however that the urea has moved. Thus if we can repeat the reductions in acidity with a second addition, then we should be closer to understanding the effects of urea and carbon on the water quality.

These findings suggested the movement of the plume is generally in agreement with the hydrology. The concentrations found in May 1999 was not entirely hypothetical, since the value agreed to that estimated with dilution. Thus soil samples were collected at about a depth of 0.5 m throughout the sandpit ( Map 3), to determine if the urea is mobile ( the literature suggested that it may adhere to clay) or mainly adhered to sand/till and to define the extent of the urea plume.

In Map 3 the values reported based on dry weight of the soil are plotted, when converted to concentrations reflecting 20 % moisture content. These values reflect concentrations of urea which are measured in the water ranging around MPS 13 from 2386 mg/L to 7629 mg/L in estimated porewater and around MPS 11 from 2151 mg/L to 3900 mg/L (**Table 21) .**
Although we have now found the plume, but if we assume that no dilution as taken place urea would be degraded , but on the other hand if it is diluted, then nothing has happened.
As can be noted from the water quality the order of magnitude of the urea concentration and agrees quite well, but we do not know which assumption is correct. The hydrological data were therefore submitted to the critical eye of the hydro-geologist.

## 5.2 Unconfined Shallow Ground Water Flow

Dr. Albert Vonhof reviewed the data base and essentially found it to be insufficient for various reasons. We will use the stored samples and possibly retroactive fill in some of the more relevant information and use the database to design and implement the second experiment. It should be noted, that given the remoteness of the site and the costs associated with each sampling trip together with about one months delay with which the data are generated, generates a clearer view with hindsight.

### 5.2.1 Review of Database

A large amount of data has been collected in the Sandpit area since 1997. Two main groups of data are present. These are water level measurements and chemical data.

The layout of the shallow piezometers are given in Map 2 a and Map 2b.

Water level measurements.

The frequency of the water level measurements in the piezometers is shown in Table 18. Only those piezometers, which are considered essential and/or crucial for the construction of the configuration of the watertable, i.e. the determination of the direction of groundwater flow, are shown in this table. The data in the table shows the elevation of the watertable over the period from September to August of the following year for 3 consecutive yearly periods. Table 18 shows that:

- Excellent data was collected in 11 months over the period from September 1997 to August 1998,

- During the period from September 1998 to August 1999 data was only collected in 9 different month. Of the 9 months with data, only the months of September, October and July have sufficient data. The other months are missing crucial data points for the construction of the configuration of the watertable,

- During the period from September 1999 to August 2000 data was collected only in 4 different month. Only 2 months (May & August) have sufficient data for the construction of the configuration of the watertable.

The configuration of the watertable over the period from September 1997 to October 1998 has been shown in a previous report as a series of sequential watertable maps. In this latter report it was also shown, that the direction of groundwater flow is very dynamic and varies from month to month.

To determine if the elevation of the water level over the period from September to August (the following year) changes in the Sandpit Area, the data from a selected number of piezometers was plotted for 1997-1998 and 1998-1999 (Figures 47 and 48, respectively). These figures show that:

- From September 1997 to August 1998 the change in the elevation of the water levels is relatively uniform between sequential month as well as between piezometers,

- From September 1998 to August 1999 the change in the elevation of the water levels is relatively uniform between sequential month, however the change in elevation of the water level between piezometers shows much greater variability than in the previous period.

In other words, the configuration of the watertable over the period 1998-1999 will differ considerably from the previous period and in all likelihood also the direction of groundwater flow. Unfortunately the data collected during most of the 1998-1999 period is inadequate for the construction of the watertable maps and the same holds true for the data collected over the 1999-2000 period. As a result no detailed information on the direction of groundwater flow is available from October 1998 to the present. Therefore we have to assume that the urea plume is distributed over a larger area then can be monitored from the piezometer locations.

Chemical Data.

Three different types of samples for chemical analysis have been collected over the time period from September 1997 to May 2000. These are:

- Water samples for major ion and trace metal concentration obtained from the piezometers,

- Water samples for nitrogen analysis obtained from the piezometers and

- Solid samples of sand, collected about 0.5 m below surface were obtained between the origine ( MSU- A and MSU-B) and the piezometers where urea had arrived.

The sediment samples collected from various locations within the Sandpit Area are given in Map 3. Table 19 summarizes the data collection events for the different types of samples. Table 19 shows that 9 water samples with a complete analysis, i.e. major ions and trace ions, were collected over a 964 day period since the addition of the urea to the sandpit. In addition, 3 water samples were collected from the piezometers, which have a partial analysis. The sampling interval varies from 1 day to 7.5 months. The piezometers with the highest overall frequency of sampling are MSP-11 and MSP-13 (12x), followed by MSP-1 (11x), MSP-7, MSP-9, MSP-12, MSU-A (10x) and MSU-B, MSP-5, MSP-10 (9x). The other piezometers considered here were only sampled occasionally. All samples have been stored and could be analysed if needed.

The collection of water samples for N analysis was started 260 days after the addition of the urea. Only piezometers MSP-11 and MSP-13 were sampled on a somewhat regular basis, with a sampling interval ranging from 1-7.5 month. All piezometers, considered here, were sampled for N analysis on June 27, 1999 and December 7, 1999 (day 644 and 807, resp.).

9 pore water samples for N analysis were obtained on September 21, 1999 (day 730). An additional 4 pore water samples were obtained on December 7, 1999 (day 807).

An overview of the elapsed time when the various types of samples were taken subsequent to the addition of the urea in the Sandpit Area is shown in Figure 49.

Urea, a nitrogen compound, is highly soluble in water. In an environment essentially void of nitrogen in the groundwater it is an excellent tracer. The nitrogen concentration in the groundwater has been measured as $NO_3$, $NH_3$ and TKN. The TKN value reflects the "organic" nitrogen, which is derived, in this case, primarily from the urea. The latter, in all likelihood, also contributes to the $NH_3$ concentration, as anticipated due to the microbial activity.

The concentration of the various nitrogen compounds in the groundwater samples from the various piezometers for 2 different dates in 1999 is shown in Figure 50. This figure shows that:

- The $NO_3$ concentration for the piezometers is very similar for both dates and ranges from 0.09-0.44 mg/l. Several piezometers (MSU-B, MSP-1, MSP-11, MSP-12 & MSP-13) are below the detection limit for one or both of the dates of sampling. The only piezometer with a $NO_3$ concentration greater than the above range is MSU-A, which has a concentration of $NO_3$ ranging from 1.3-2.5 mg/l.

- The $NH_3$ concentration for the piezometers shows a much greater variability between the 2 dates of sampling (June 27, 1999 & Dec. 7, 1999). MSP-1 shows that the $NH_3$ concentration on June 27 is 5.9 mg/l and drops to 1.5 mg/l on December 7. MSP-5, MSP-7, MSP-9 & MSP-10 show that the $NH_3$ concentration on June 27 ranges from 0.06-0.11 mg/l in these piezometers and on December 7ranges from 0.9-0.21 mg/l. The concentration of $NH_3$ is consistently higher in each of the 4 piezometers on this latter date. Piezometers MSP-11 & MSP-13 show $NH_3$ concentrations of 9.3 and 15.0 mg/l, respectively, on June 27 and concentrations of 20.0 and 41.0 mg/l, respectively. These are the highest values encountered in the Sandpit Area. MSP-12 has a similar $NH_3$ concentration for both dates (2.0 and 1.9 mg/l, resp.). MSU-A shows a trend similar to MSP-1, the $NH_3$ concentration on June 27 is 5.5 mg/l and drops to 0.13 mg/l on December 7. MSU-B was not analysed on December 7 and the trend is not known.

- The TKN concentration in the piezometers shows a trend similar to the $NH_3$ concentration. The TKN concentration is invariably higher in the water samples collected on June 27 than on December 7 from piezometers MSP-1, MSP-11, MSP-13 and MSU-A. This trend is reversed for piezometers MSP-5, MSP-7, MSP-9 and MSP-10. In these piezometers the concentration of TKN was below the detection limit on June 27 and TKN is only present in the water samples collected on December 7. The concentration on this latter date ranges from 0.73-1.6 mg/l. MSP-12 shows a similar TKN concentration for both dates (4.8 & 5.0 mg/l, resp.). MSU-B was not analysed on December 7 and the trend is not known.

Based on the analysis of the groundwater flow pattern in the Sandpit Area over the period September 1997-October 1998 the groundwater at the location of piezometers MSP-5, MSP-7, MSP-9 and MSP-10 should not have been affected by the urea amendments near MSU-A. It is, therefore, assumed that the concentration of TKN and $NH_3$ in these piezometers reflect the natural background concentration of these compounds in this area and the variation in the concentration of these 2 compounds between July and December is thought to reflect seasonal changes in the natural environment. NOTE: *This assumption is based on 2 analyses only and further analytical work may prove it to be completely wrong*.

In order to define the background more reliably, in October 2000 all piezometers in the sandpit were sampled and nitrogen compounds analysed (Table 22). With the exception of MSP-1 all values are within a background range, defined earlier. The problem with the use of a natural compound, such as urea is, that off course Moose would not read a sign " Please to dot pee here". This may explain the relatively high value at MPS -1.

MSP-1 and MSP-12 have $NH_3$ and TKN concentrations considerably higher than the assumed background values for the area. These piezometers are located north of MSU-B, the location of the second amendment of urea in the Sandpit Area. Unfortunately, the groundwater flow pattern in this part of the Sandpit Area is not well defined, because of a lack of data points. If the contention is true, that the concentration of $NH_3$ and TKN in piezometers MSP-5, MSP-7, MSP-9 and MSP-10 reflects the background value than the concentration of these compounds in MSP-1 and MSP-12 suggests an external source, i.e. MSU-B, which, in turn, suggests some northward migration of the urea from MSU-B.

Piezometers MSP-11 and MSP-13 are the only 2 piezometers with multiple nitrogen analyses on dates other than June and December 1999 (Figure 51). The first sample was taken on June 7, 1998, 259 days after the urea was added. If Figures 50 and 51 are compared, it shows that in June 1998 both piezometers have a $NH_3$ and TKN concentration much greater than the background concentration of piezometers MSP-5, MSP-7, MSP-9 and MSP-10. In other words, some of the urea added at MSU-A had already moved to MSP-11 and from MSU-B to MSP-13 on that date. The first arrival of urea at both piezometers is not known, because there are no earlier analyses. The data from June 7, 1998 does indicate that the minimum rate of groundwater flow is 1.54 cm/day, but it could be considerably greater. This problem will be addressed with looking through the sample storage.

Figure 51 shows that the maximum concentration of TKN was measured in MSP-11 in May 23, 1999 and June 27, 1999 in MSP-13. After these dates both piezometers show a decline in the concentration of TKN. However, the water taken for analysis on June 27, 1999 is after the addition of carbon (sugar) to the shallow subsurface around the 2 piezometers. A number of questions are raised by the distribution of the nitrogen versus time in these piezometers.

After this report was completed, several further samples have been collected and they are added in the same format in Figure 51a. A clear decreasing trend in both piezometers is noted after day 902 fro TKN , but unfortunately not corresponding increase in ammonia during this time . In Figure 52 acidity and conductivity in the same piezometers are presented in a comparable format. Although, after the first carbon addition to the urea plume on October 4$^{th}$ 1999, around day 644 it appeared as if the acidity decreased, but not unfortunately not consistently. Thus the questions remain listed below.

1. When did the urea arrive at the sampling points?

2. Is the maximum shown by both curves the real maximum concentration of the urea plume flowing by the sampling points?

3. What is the shape of the urea plume? Diffuse or peak-like?

4. What is the areal distribution of the TKN concentration in the plume?

5. Is the decline in the TKN concentration after the addition of carbon the result of biochemical processes or does it simply reflect the passing of a concentration plume?

Most of these questions cannot be answered, because of an incomplete database. However, a partial answer to question 5 may be possible, because of the trend shown by $NH_3$.

Figure 51 illustrates that the $NH_3$ concentration only increases slightly in the 2 piezometers prior to the addition of carbon, even though the concentration of TKN increases significantly. Subsequent to the addition of the carbon, after an initial drop, the $NH_3$ concentration increases quite significantly in both piezometers, while the TKN concentration drops rapidly.

If biochemical processes breaking down the urea and releasing $NH_3$ are accelerated by the addition of carbon to the subsurface environment than this could account for the noted increase in $NH_3$. However, the drop in the concentration of the TKN could simply be due to a moving urea plume (minimum movement from June 27, 1999-December 7, 1999 is 2.5m). The increase in the $NH_3$ concentration could be due to increased biochemical activity as a result of carbon addition and not necessarily signal an accelerated breakdown of TKN. In fact this is what we would like to think, but we can not be sure.

It is unfortunate, that no control sites were established to determine the trend of N in a passing urea plume. In addition sampling points upstream and downstream with respect to the direction of groundwater flow from the 2 piezometers are necessary. The upstream sampling points would have provided information on the concentration and shape of the plume and the potential attenuation of the urea plume with distance from its source. The downstream points would have yielded information on the attenuation resulting from the addition of carbon. The time interval between sequential samples would have to be much shorter to obtain the necessary data. We hope this can be rectified with the stored samples.

The sediment samples collected from boreholes drilled in a number of locations within the Sandpit Area. These samples are located in the vicinity of MSU-A, MSU-B, MSP-11 & MSP-

13 and also between MSU-A & MSP-11, MSP-11 & MSP-13, MSU-B & MSP-13 and MSP-13 & M72A. Three rounds of sampling were conducted: June 27, September 21 and December 7, 1999 (Table 19). The samples collected in June were not analysed yet, since we did not want to analyse into the dark. The samples were stored frozen.

Different locations of the sampled during each round of sampling round to cover areas in between relevant areas. The largest number of samples was collected in September. The result of the TKN analyses for the September samples is shown in Map 3. This map illustrates that considerable concentrations of TKN are present at the locations described above. The areal distribution of the values is similar to the changes versus time observed in the water samples from piezometers MSP-11 & 13. This indicates not only that the urea placed in the vicinity of MSU-A & B has moved quite extensively, but also that the distribution of the concentration in the plume may be less than uniform. It appears that part of the plumes from the amendment sites is moving in the direction of M72C.

Figure 49 shows that on the day the soil samples were taken, the piezometers were not sampled for nitrogen. This is unfortunate, because the concentrations found in the various borehole locations can not be correlated to the water samples from the piezometers. Although 4 more boreholes were drilled and sampled in December 1999, their location is different from the September ones and the results from the December samples can, therefore, not be used to determine the evolution of the plume.

### 5.2.2 Calculation of Urea Concentration.

The use of a trapezoid between urea hole UA1, M72C and urea hole UB14 **(Report: Calculation of Urea Concentration, Map 2)** may or may not cover the complete area of urea movement. Borehole c & d (Map 2) show that there is, in all likelihood, movement across the side of the trapezoid UA1-M72C ( Map 3). There are no data points between UA1 and borehole d. Groundwater flow direction based on the maps showing the configuration of the watertable (previous report) clearly show the possibility of potential urea transport from the urea holes in a south-southeasterly direction. Unfortunately, as has been pointed out above, the current database and distribution of data points is inadequate to define the areal extent, concentration and changes with time of the urea plumes emanating from the urea holes: UA1-14 & UB1-14.

The theoretical calculation of the urea concentration, based on the area of the plume (trapezoid), input concentration and subsequent dilution appears to support the concentration observed in MSP-11. However, there is no information presented to substantiate this similarity in results other than the similarity in value. Based on the current database, the calculation of the urea concentration in the Sandpit Area is premature.
We hope that with the completion of the stored samples, this will be possible.

### 5.2.3 Conclusions

The distribution of the concentration of the TKN concentration in the area shows that the groundwater flow pattern is rather complex and the collected chemical data supports a similar conclusion reached after water level measurements in the piezometers over the period September 1997 to October 1998 were evaluated.

The data collected thus far, clearly shows that the urea added to the shallow subsurface has moved, but the plume movement is very complex. Irrespective of the complexity, The Sandpit Area remains an ideal test site, because in geological terms it is relatively uniform and installation of monitoring points is relatively easy and cheap. However, it does require a vastly increased network of sampling points and regular monitoring in order to obtain the data necessary to define the movement and attenuation of the plume and to monitor the effect of other amendments, such as carbon, to the urea plume.

One of the main problems with this study is that it is not a question of **not collecting** data from a limited number of sampling points, but the unsystematic the data collection. For example, (a) One set of samples for a specific parameter is collected, but not in all sampling points. This severely limits the usefulness of the data for comparative and correlation purposes. (b) Data collection was conducted in spurts, with very large time gaps. As a result the data base is inadequate for detailed trend analysis of the evolution of the plumes in the shallow subsurface. Although it is hoped, with this first round of data analysis, and the addition which is forthcoming from the stored data , that a better understanding can be created.

On the positive side however, we now have a condition, which allows us to design a second urea plume much better.

### 5.3 The Second Urea plume experiment

Based on the laboratory experiment where sediments from the sandpit were incubated with amendment. The set up of the tubes is given in Table 23. The biomagic experiment was run at both room temperature and in the refrigerator. The results show
that urea applied with sugar and yeast extract to MSP-11 water and MSU-B sediment can increases the pH of top water for 2 - 4 pH units for both compared to the control (MSP-11 water and MSU-B sed only). If urea was applied by itself did not increase the pH of the water very much Table 24a.

In order to obtain a measurable unit the sugar used in the field and in the experiments was calibrated against glucose concentrations ( Figure 52). As we know the addition of sugar to the tubes, we can now derived a sugar consumed unit for the biomagic experiment (Table 24b). Unfortunately, the sugar consumed per day, which would reflect some microbial activity. Although this experiment was set up badly, it does support the overall concept and the theoretical work carried out by G. Ferris at U of T. It will serve to set up a second experiment, reflecting the new field conditions created in fall 2000.

Using a somewhat similar approach for evaluating the Sand pit data ( Table 25), a ratio of sugar to urea used in the field is derived. The field experiment shows that adding sugar and yeast extract to the area around MSP-11 and MSP-13 , where the highest TKN values were reported, a ratio of urea:sugar:yeast extract = 1:2:0.2 appears to have assisted in degradation of urea. A consumption rate of urea can be estimated at 10.8 - 14.4 mg/day.

When adding sugar alone to those two locations, the urea consumption per day dropped to 3 - 5 mg. These results seem to tell us yeast extract helped the degradation of urea or there is not enough urea left in the locations. This would suggest that yeast extract is important. Therefore we looked at the content of yeast extract which contains a lot of carbohydrate (17%) and nitrogen (10.9%) and other inorganic. Clearly this would assist microbial activity.

The second field experiment is going to set up around MSP-12 (as background), MSP-11 and MSP-13 (Table 26). In the new set up, three circles will be made with 2 $m^2$ diameter and 1 m deep application of urea (Map 4). The calculations based on the hydrological considerations given in Table 26. The amount of urea applied (11 kg/circle) is the same as that applied September 21st, 1997 to achieve the same concentrations then were estimated to be present in beginning.

This will at least in part facilitate, that the second experiment will shed light on the first one. The amount of sugar will be 22 kg/circle, bu the amount of yeast extract will be reduced to 0.22 kg/circle, which gave a ratio of urea : sugar : yeast = 1 : 2 : 0.02, instead of the ratio of 1 : 2 : 0.2 used in the field. Because yeast extract is relatively expensive, comparing to Demora sugar and urea fertilizer.

## 6.0 CONCLUSIONS

We hope that with this review, and summary of the data, and the steps taken from this review, will shed more light on the first set up and data in the sandpit. As the experiment is set up just before winter, we hope to have many aspects defined prior to major activities in the field. With the cold temperatures, not much activity is anticipated to take place in the field. It will buy time to solicit the input from experts in this field. Although no final conclusion can be reached, the field and laboratory experiments are somewhat encouraging, albeit the complexity. There is not sufficient evidence to terminate the approach and hence we will continue. The field / lab chemistry of the new set up is given in Table 27. The new situation covers a wide range of acidities, 4 locations with normal pH values and the rest in the expected low range. There is certainly now a range of conditions which can be tested to reach the desired answers, and this should be successful, given the extensive background available in the sandpit.

**Table 1: Decant Pond**

| ZONE | LAYER | ZONE | | Constant Head | Drains | River Leakage | Recharge | 2 Tailings Boundary Tailings Layer 1 | 4 Decant Pond Layer 1 | 8 South of Tailings Incl Div Ditch Layer 1 | 9 East of Decant Pond Layer 1 | 11 E.of Mud Lake-North of Decant Layer 1 | 13 Tailings Boundary NOT TAILINGS Layer 2 | 14 Decant Pond Layer 2 | 18 South of Tailings Incl Div Ditch Layer 2 | 19 East of Decant Pond Layer 2 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 4 | 1 | Decant Pond | IN | 0 | 0 | 94 | 697 | 173 | | 57 | 804 | 216 | | 2 | | |
| | | | OUT | 0 | 0 | -1,512 | 0 | -36 | | 0 | -39 | -71 | | -359 | | |
| 14 | 2 | Decant Pond | IN | 0 | 0 | 5,010 | 0 | | 359 | | | | 15 | | 0 | 8 |
| | | | OUT | 0 | 0 | -50 | 0 | | -2 | | | | -992 | | 0 | -7 |
| 25 | 3 | Decant Pond | IN | 0 | 0 | 5,833 | 0 | | | | | | | 4,363 | | |
| | | | OUT | 0 | 0 | -142 | 0 | | | | | | | -41 | | |
| 35 | 4 | Decant Pond | IN | 0 | 0 | 1,731 | 0 | | | | | | | | | |
| | | | OUT | 0 | 0 | 0 | 0 | | | | | | | | | |

| ZONE | LAYER | ZONE | | 21 E.of Mud Lake-North of Decant Layer 2 | 24 Tailings Boundary NOT TAILINGS Layer 3 | 25 Decant Pond Layer 3 | 29 South of Tailings Incl Div Ditch Layer 3 | 30 East of Decant Pond Layer 3 | 32 E.of Mud Lake-North of Decant Layer 3 | 34 Tailings Boundary NOT TAILINGS Layer 4 | 35 Decant Pond Layer 4 | 39 South of Tailings Incl Div Ditch Layer 4 | 40 East of Decant Pond Layer 4 | 42 E.of Mud Lake-North of Decant Layer 4 | TOTAL |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 4 | 1 | Decant Pond | IN | | | | | | | | | | | | 16,460 |
| | | | OUT | | | | | | | | | | | | 14,417 |
| 14 | 2 | Decant Pond | IN | 1 | | 41 | | | | | | | | | 16,475 |
| | | | OUT | -20 | | -4,363 | | | | | | | | | 6,709 |
| 25 | 3 | Decant Pond | IN | | 110 | | 0 | 368 | 37 | | 211 | | | | 8,479 |
| | | | OUT | | -5,423 | | -4 | -62 | -729 | | -4,521 | | | | -12,455 |
| 35 | 4 | Decant Pond | IN | | | 4,521 | | | | 167 | | 0 | 520 | 41 | -7,022 |
| | | | OUT | | | -211 | | | | -5,537 | | -5 | -314 | -913 | -15,733 |

Table 2: Hydraulic Conductivities defined in the model

| # | Color | Kx [cm/s] | Ky [cm/s] | Kz [cm/s] |
|---|---|---|---|---|
| 1 | | 0.001 | 0.001 | 0.002 |
| 2 | | 9E-05 | 9E-05 | 1E-05 |
| 3 | | 0.0001 | 0.0001 | 1E-05 |
| 4 | | 0.015 | 0.015 | 0.0015 |
| 5 | | 4E-05 | 4E-05 | 4E-06 |
| 6 | | 1.4E-05 | 1.4E-05 | 1.4E-05 |
| 7 | | 2.5E-05 | 2.5E-05 | 2.5E-06 |
| 8 | | 0.0047 | 0.0047 | 0.001 |
| 9 | | 1E-06 | 1E-06 | 1E-07 |
| 10 | | 0.021 | 0.021 | 0.021 |

Table 3: Differences between Observed and Calculated Heads in the piezometers located around Diversion Ditch

| Piezo# | Easting | Northimg | Obs. | Calc. | Calc.-Obs | Calc.-Obs |
|---|---|---|---|---|---|---|
| | [ft] | [ft] | [ft] | [ft] | [ft] | [m] |
| M9 | 11885 | 15250 | 1360.90 | 1358.63 | -2.32 | -0.71 |
| M10 | 11925 | 15205 | 1359.30 | 1359.03 | -0.35 | -0.11 |
| M20B | 11363 | 14288 | 1359.30 | 1355.65 | -3.71 | -1.13 |
| M21 | 11432 | 14553 | 1359.30 | 1355.72 | -3.64 | -1.11 |
| M22 | 10740 | 14355 | 1364.90 | 1355.81 | -9.12 | -2.78 |
| M42 | 11560 | 14780 | 1365.70 | 1355.23 | -10.49 | -3.20 |
| M46 | 12020 | 15370 | 1361.00 | 1361.18 | 0.11 | 0.03 |
| M47 | 12055 | 15330 | 1353.30 | 1351.76 | -1.61 | -0.49 |
| M50 | 10670 | 14300 | 1352.90 | 1355.82 | 2.90 | 0.88 |
| M52 | 12090 | 15260 | 1352.20 | 1351.67 | -0.60 | -0.18 |
| M77A | 11342 | 14030 | 1352.40 | 1355.00 | 2.54 | 0.77 |
| M77B | 11344 | 14032 | 1352.80 | 1355.00 | 2.15 | 0.66 |
| M78A | 11196 | 14961 | 1358.60 | 1356.15 | -2.54 | -0.77 |
| M78B | 11201 | 14961 | 1358.80 | 1356.12 | -2.77 | -0.84 |
| M82 | 11318 | 14375 | 1359.20 | 1355.75 | -3.48 | -1.06 |
| H1 | 11705 | 15300 | 1366.20 | 1363.04 | -3.16 | -0.96 |
| H2 | 11360 | 15220 | 1364.70 | 1362.43 | -2.33 | -0.71 |
| H3 | 11225 | 15310 | 1365.10 | 1364.35 | -0.74 | -0.23 |

Table 4:  Description of the budget zones

| Zone # | Layer # | Description |
|---|---|---|
| 1 | 1 | Town Site |
| 2 | 1 | Tailings Boundary - Tailings Material |
| 4 | 1 | Decant Pond |
| 5 | 1 | Kalin Canyon |
| 6 | 1 | Mud Lake |
| 7 | 1 | West of Kalin Canyon |
| 8 | 1 | South of Tailings (includes Diversion Ditch) |
| 9 | 1 | East of Decant Pond |
| 10 | 1 | North of Tailings to Mud Lake |
| 11 | 1 | East of Mud Lake - North of Decant Pond |
| 12 | 2 | Town Site |
| 13 | 2 | Tailings Boundary - NOT Tailings Material |
| 14 | 2 | Decant Pond |
| 15 | 2 | Kalin Canyon |
| 16 | 2 | Mud Lake |
| 17 | 2 | West of Kalin Canyon |
| 18 | 2 | South of Tailings (includes Diversion Ditch) |
| 19 | 2 | East of Decant Pond |
| 20 | 2 | North of Tailings to Mud Lake |
| 21 | 2 | East of Mud Lake - North of Decant Pond |
| 22 | 2 | Tailings Boundary - Tailings Material |
| 23 | 3 | Town Site |
| 24 | 3 | Tailings Boundary - NOT Tailings Material |
| 25 | 3 | Decant Pond |
| 26 | 3 | Kalin Canyon |
| 27 | 3 | Mud Lake |
| 28 | 3 | West of Kalin Canyon |
| 29 | 3 | South of Tailings (includes Diversion Ditch) |
| 30 | 3 | East of Decant Pond |
| 31 | 3 | North of Tailings to Mud Lake |
| 32 | 3 | East of Mud Lake - North of Decant Pond |
| 33 | 4 | Town Site |
| 34 | 4 | Tailings Boundary - NOT Tailings Material |
| 35 | 4 | Decant Pond |
| 36 | 4 | Kalin Canyon |
| 37 | 4 | Mud Lake |
| 38 | 4 | West of Kalin Canyon |
| 39 | 4 | South of Tailings (includes Diversion Ditch) |
| 40 | 4 | East of Decant Pond |
| 41 | 4 | North of Tailings to Mud Lake |
| 42 | 4 | East of Mud Lake - North of Decant Pond |

**Table 5: Town Site**

| ZONE | LAYER | ZONE | | Constant Head | Drains | River Leakage | Recharge | 1 Town Site Layer 1 | 7 West of Kalin Canyon Layer 1 | 8 South of Tailings Incl Div Ditch Layer 1 | 12 Town Site Layer 2 | 17 West of Kalin Canyon Layer 2 | 18 South of Tailings Incl Div Ditch Layer 2 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1 | South of Tailings - Town Site | IN | 448 | 0 | 0 | 22,620 | | 1 | 269 | 2,066 | | |
| | | | OUT | -2,731 | 0 | 0 | 0 | | -20 | -404 | -22,249 | | |
| 12 | 2 | South of Tailings - Town Site | IN | 3,713 | 0 | 0 | 0 | 22,249 | | | | 4 | 244 |
| | | | OUT | -8,589 | 0 | 0 | 0 | -2,066 | | | | -318 | -1,049 |
| 23 | 3 | South of Tailings - Town Site | IN | 5,531 | 0 | 0 | 0 | | | | 18,763 | | |
| | | | OUT | -11,285 | 0 | 0 | 0 | | | | -4,574 | | |
| 33 | 4 | South of Tailings - Town Site | IN | 5,382 | 0 | 0 | 0 | | | | | | |
| | | | OUT | -9,530 | 0 | 0 | 0 | | | | | | |

| ZONE | LAYER | ZONE | | 23 Town Site Layer 3 | 26 Kalin Canyon Layer 3 | 28 West of Kalin Canyon Layer 3 | 29 South of Tailings Incl Div Ditch Layer 3 | 33 Town Site Layer 4 | 36 Kalin Canyon Layer 4 | 38 West of Kalin Canyon Layer 4 | 39 South of Tailings Incl Div Ditch Layer 4 | TOTAL |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1 | South of Tailings - Town Site | IN | | | | | | | | | 19,846 |
| | | | OUT | | | | | | | | | -5,557 |
| 12 | 2 | South of Tailings - Town Site | IN | 4,574 | | | | | | | | 24,420 |
| | | | OUT | -18,763 | | | | | | | | -20,305 |
| 23 | 3 | South of Tailings - Town Site | IN | | 1 | 14 | 255 | 3,645 | | | | -5,736 |
| | | | OUT | | -73 | -840 | -995 | -10,440 | | | | -42,379 |
| 33 | 4 | South of Tailings - Town Site | IN | 10,440 | | | | | 2 | 9 | 249 | -15,819 |
| | | | OUT | -3,645 | | | | | -75 | -543 | -2,290 | -27,753 |

## Table 6: Tailings Boundary - Tailings Material

| ZONE | LAYER | ZONE | | Constant Head | Drains | River Leakage | Recharge | 2 Tailings Boundary Tailings Layer 1 | 4 Decant Pond Layer 1 | 5 Kalin Canyon Layer 1 |
|---|---|---|---|---|---|---|---|---|---|---|
| 2 | 1 | Tailings Boundary - TAILINGS | IN | 0 | 0 | 34 | 23,737 | | 36 | 0 |
| | | | OUT | 0 | 0 | -51 | 0 | | -173 | -391 |
| 22 | 2 | Tailings Boundary - TAILINGS | IN | 0 | 0 | 0 | 0 | 1,622 | | |
| | | | OUT | 0 | 0 | 0 | 0 | 0 | | |

| ZONE | LAYER | ZONE | | 8 South of Tailings Incl Div Ditch Layer 1 | 10 North of Tailings to Mud Lake Layer 1 | 13 Tailings Boundary NOT TAILINGS Layer 2 | 18 South of Tailings Incl Div Ditch Layer 2 | 22 Tailings Boundary Tailings Layer 2 | 24 Tailings Boundary NOT TAILINGS Layer 3 | TOTAL |
|---|---|---|---|---|---|---|---|---|---|---|
| 2 | 1 | Tailings Boundary - TAILINGS | IN | 43 | 252 | 47 | 0 | 0 | | 25,641 |
| | | | OUT | -189 | -303 | -21,272 | -147 | -1,622 | | -21,698 |
| 22 | 2 | Tailings Boundary - TAILINGS | IN | | | 295 | | | 1 | -21,178 |
| | | | OUT | | | -1,711 | | | -207 | -24,718 |

Table 7: Tailings Boundary - NOT TAILINGS

| ZONE | LAYER | ZONE | | Constant Head | Drains | River Leakage | Recharge | 2 Tailings Boundary Tailings Layer 1 | 8 South of Tailings Incl Div Ditch Layer 1 | 13 Tailings Boundary NOT TAILINGS Layer 2 | 14 Decant Pond Layer 2 | 15 Kalin Canyon Layer 2 | 18 South of Tailings Incl Div Ditch Layer 2 | 20 North of Tailings to Mud Lake Layer 2 | 22 Tailings Boundary Tailings Layer 2 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 13 | 2 | Tailings Boundary NOT TAILINGS | IN | 0 | 0 | 618 | 0 | 21,272 | 0 | | 992 | 380 | 654 | 128 | 1,711 |
| | | | OUT | 0 | 0 | -1 | 0 | -47 | -12 | | -15 | -3,485 | -3,615 | -1,162 | -295 |
| 24 | 3 | Tailings Boundary NOT TAILINGS | IN | 0 | 0 | 1,771 | 0 | | | 18,623 | | | | | 207 |
| | | | OUT | 0 | 0 | 0 | 0 | | | -1,467 | | | | | -1 |
| 34 | 4 | Tailings Boundary NOT TAILINGS | IN | 0 | 0 | 1,484 | 0 | | | | | | | | |
| | | | OUT | 0 | 0 | 0 | 0 | | | | | | | | |

| ZONE | LAYER | ZONE | | 24 Tailings Boundary NOT TAILINGS Layer 3 | 25 Decant Pond Layer 3 | 26 Kalin Canyon Layer 3 | 29 South of Tailings Incl Div Ditch Layer 3 | 31 North of Tailings to Mud Lake Layer 3 | 34 Tailings Boundary NOT TAILINGS Layer 4 | 35 Decant Pond Layer 4 | 36 Kalin Canyon Layer 4 | 39 South of Tailings Incl Div Ditch Layer 4 | 41 North of Tailings to Mud Lake Layer 4 | TOTAL |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 13 | 2 | Tailings Boundary NOT TAILINGS | IN | 1,467 | | 0 | 31 | | | | | | | 38,971 |
| | | | OUT | -18,623 | | 0 | 0 | | | | | | | -3,567 |
| 24 | 3 | Tailings Boundary NOT TAILINGS | IN | | 5,423 | 801 | 240 | 411 | 2,989 | | | | | 13,471 |
| | | | OUT | | -110 | -5,507 | -1,453 | -2,918 | -19,008 | | | | | -35,920 |
| 34 | 4 | Tailings Boundary NOT TAILINGS | IN | 19,008 | | | | | | 5,537 | 608 | 2,050 | 446 | -6,803 |
| | | | OUT | -2,989 | | | | | | -167 | -11,173 | -11,875 | -2,930 | -37,420 |

Table 8: Kalin Canyon

| ZONE | LAYER | ZONE | | Constant Head | Drains | River Leakage | Recharge | 2 Tailings Boundary Tailings Layer 1 | 5 Kalin Canyon Layer 1 | 7 West of Kalin Canyon Layer 1 | 8 South of Tailings Incl Div Ditch Layer 1 | 10 North of Tailings to Mud Lake Layer 1 | 13 Tailings Boundary NOT TAILINGS Layer 2 | 15 Kalin Canyon Layer 2 | 16 Mud Lake Layer 2 | 17 West of Kalin Canyon Layer 2 | 18 South of Tailings Incl Div Ditch Layer 2 | 20 North of Tailings to Mud Lake Layer 2 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 5 | 1 | Kalin Canyon | IN | 0 | 0 | 0 | 8,988 | 391 | | 85 | | 651 | | 268 | | 0 | | |
| | | | OUT | 0 | 0 | 0 | 0 | 0 | | -647 | | -125 | | -8,885 | | -725 | | |
| 15 | 2 | Kalin Canyon | IN | 0 | 0 | 0 | 0 | | 8,885 | 6,228 | 41 | 1,557 | 3,485 | | 0 | 1,051 | 27 | 32 |
| | | | OUT | 0 | 0 | -1,439 | 0 | | -268 | -28 | 0 | -18 | -380 | | -323 | -2,643 | -3,379 | -0 |
| 26 | 3 | Kalin Canyon | IN | 0 | 0 | 0 | 0 | | | | | | 0 | 18,688 | | | | 2,902 |
| | | | OUT | 0 | 0 | -1,419 | 0 | | | | | | -0 | -5,843 | | | | 0 |
| 36 | 4 | Kalin Canyon | IN | 0 | 0 | 0 | 0 | | | | | | | | | | | |
| | | | OUT | 0 | 0 | -1,471 | 0 | | | | | | | | | | | |

| ZONE | LAYER | ZONE | | 23 South of Tailngs Town Site Layer 3 | 24 Tailings Boundary NOT TAILINGS Layer 3 | 26 Kalin Canyon Layer 3 | 27 Mud Lake Layer 3 | 28 West of Kalin Canyon Layer 3 | 29 South of Tailings Incl Div Ditch Layer 3 | 31 North of Tailings to Mud Lake Layer 3 | 33 South of Tailngs Town Site Layer 4 | 34 Tailings Boundary NOT TAILINGS Layer 4 | 36 Kalin Canyon Layer 4 | 37 Mud Lake Layer 4 | 38 West of Kalin Canyon Layer 4 | 39 South of Tailings Incl Div Ditch Layer 4 | 41 North of Tailings to Mud Lake Layer 4 | TOTAL |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 5 | 1 | Kalin Canyon | IN | | | | | | | | | | | | | | | 23,197 |
| | | | OUT | | | | | | | | | | | | | | | 12,814 |
| 15 | 2 | Kalin Canyon | IN | | | 5,843 | | | | | | | | | | | | 29,039 |
| | | | OUT | | | -18,688 | | | | | | | | | | | | -10,924 |
| 26 | 3 | Kalin Canyon | IN | 73 | 5,507 | | 68 | 861 | 46 | 4,931 | | | 10,198 | | | | | 19,241 |
| | | | OUT | -1 | -801 | | -11,357 | -2,803 | -4,794 | 0 | | | -16,215 | | | | | -35,418 |
| 36 | 4 | Kalin Canyon | IN | | | 16,215 | | | | | 75 | 11,173 | | 80 | 1,035 | 44 | 5,432 | 5,897 |
| | | | OUT | | | -10,198 | | | | | -2 | -608 | | -12,835 | -3,882 | -5,082 | 0 | -26,711 |

**Table 9: Mud Lake**

| ZONE | LAYER | ZONE | | Constant Head | Drains | River Leakage | Recharge | 6 Mud Lake Layer 1 | 7 West of Kalin Canyon Layer 1 | 10 North of Tailings to Mud Lake Layer 1 | 11 E.of Mud Lake-North of Decant Layer 1 | 15 Kalin Canyon Layer 2 | 16 Mud Lake Layer 2 | 17 West of Kalin Canyon Layer 2 | 20 North of Tailings to Mud Lake Layer 2 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 6 | 1 | Mud Lake | IN | 0 | 0 | 837 | 0 | | 235 | 81 | 4,769 | | 49 | | |
| | | | OUT | 0 | 0 | -4,912 | 0 | | -0 | -0 | -6 | | -30 | | |
| 16 | 2 | Mud Lake | IN | 0 | 0 | 22 | 0 | 30 | | | | 323 | | 1,053 | 7 |
| | | | OUT | 0 | 0 | -4,657 | 0 | -49 | | | | 0 | | -13 | -0 |
| 27 | 3 | Mud Lake | IN | 0 | 0 | 1,227 | 0 | | | | | | 44 | | |
| | | | OUT | 0 | 0 | -17,319 | 0 | | | | | | -152 | | |
| 37 | 4 | Mud Lake | IN | 0 | 0 | 3 | 0 | | | | | | | | |
| | | | OUT | 0 | 0 | -22,442 | 0 | | | | | | | | |

| ZONE | LAYER | ZONE | | 21 E.of Mud Lake-North of Decant Layer 2 | 26 Kalin Canyon Layer 3 | 27 Mud Lake Layer 3 | 28 West of Kalin Canyon Layer 3 | 31 North of Tailings to Mud Lake Layer 3 | 32 E.of Mud Lake-North of Decant Layer 3 | 36 Kalin Canyon Layer 4 | 37 Mud Lake Layer 4 | 38 West of Kalin Canyon Layer 4 | 41 North of Tailings to Mud Lake Layer 4 | 42 E.of Mud Lake-North of Decant Layer 4 | TOTAL |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 6 | 1 | Mud Lake | IN | | | | | | | | | | | | -40,548 |
| | | | OUT | | | | | | | | | | | | -46,520 |
| 16 | 2 | Mud Lake | IN | 2,076 | | 152 | | | | | | | | | -39,344 |
| | | | OUT | -0 | | -44 | | | | | | | | | -40,816 |
| 27 | 3 | Mud Lake | IN | | 11,357 | | 1,079 | 646 | 3,590 | | 1,430 | | | | -17,995 |
| | | | OUT | | -68 | | -14 | 0 | -103 | | -47 | | | | -19,498 |
| 37 | 4 | Mud Lake | IN | | | 47 | | | | 12,835 | | 1,138 | 3,399 | 5,195 | 20,587 |
| | | | OUT | | | -1,430 | | | | -80 | | -14 | 0 | -205 | 18,855 |

Table 10: West of Kalin Canyon

| ZONE | LAYER | ZONE | | Constant Head | Drains | River Leakage | Recharge | 1 Town Site Layer 1 | 5 Kalin Canyon Layer 1 | 6 Mud Lake Layer 1 | 7 West of Kalin Canyon Layer 1 | 10 North of Tailings to Mud Lake Layer 1 | 12 Town Site Layer 2 | 15 Kalin Canyon Layer 2 | 16 Mud Lake Layer 2 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 7 | 1 | West of Kalin Canyon | IN | 155 | 0 | 7 | 40,358 | 20 | 647 | 0 | | 13 | | 28 | |
| | | | OUT | -3,250 | 0 | -18 | 0 | -1 | -85 | -235 | | -33 | | -6,228 | |
| 17 | 2 | West of Kalin Canyon | IN | 1,792 | 0 | 0 | 0 | | 725 | | 32,070 | | 318 | 2,643 | 13 |
| | | | OUT | -17,270 | 0 | 0 | 0 | | 0 | | -771 | | -4 | -1,051 | -1,053 |
| 28 | 3 | West of Kalin Canyon | IN | 1,883 | 0 | 0 | 0 | | | | | | | | |
| | | | OUT | -12,065 | 0 | 0 | 0 | | | | | | | | |
| 38 | 4 | West of Kalin Canyon | IN | 2,010 | 0 | 0 | 0 | | | | | | | | |
| | | | OUT | -13,201 | 0 | 0 | 0 | | | | | | | | |

| ZONE | LAYER | ZONE | | 17 West of Kalin Canyon Layer 2 | 20 North of Tailings to Mud Lake Layer 2 | 23 Town Site Layer 3 | 26 Kalin Canyon Layer 3 | 27 Mud Lake Layer 3 | 28 West of Kalin Canyon Layer 3 | 33 Town Site Layer 4 | 36 Kalin Canyon Layer 4 | 37 Mud Lake Layer 4 | 38 West of Kalin Canyon Layer 4 | TOTAL |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 7 | 1 | West of Kalin Canyon | IN | 771 | 0 | | | | | | | | | 34,123 |
| | | | OUT | -32,070 | -61 | | | | | | | | | -39,209 |
| 17 | 2 | West of Kalin Canyon | IN | | | | | | 3,360 | | | | | -32,227 |
| | | | OUT | | | | | | -20,774 | | | | | -87,906 |
| 28 | 3 | West of Kalin Canyon | IN | 20,774 | | 840 | 2,803 | 14 | | | | | 4,309 | -41,122 |
| | | | OUT | -3,360 | | -14 | -861 | -1,079 | | | | | -13,243 | -61,563 |
| 38 | 4 | West of Kalin Canyon | IN | | | | | | 13,243 | 543 | 3,882 | 14 | | -31,816 |
| | | | OUT | | | | | | -4,309 | -9 | -1,035 | -1,138 | | -40,318 |

**Table 11: South of Tailings - includes Diversion Ditch**

| ZONE | LAYER | ZONE | | Constant Head | Drains | River Leakage | Recharge | 1 Town Site Layer 1 | 2 Tailings Boundary Tailings Layer 1 | 4 Decant Pond Layer 1 | 8 South of Tailings Incl Div Ditch Layer 1 | 9 East of Decant Pond Layer 1 | 12 Town Site Layer 2 | 13 Tailings Boundary NOT TAILINGS Layer 2 | 14 Decant Pond Layer 2 | 15 Kalin Canyon Layer 2 | 18 South of Tailings Incl Div Ditch Layer 2 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 8 | 1 | South of Tailings - Diversion Ditch | IN | 0 | 0 | 0 | 7,339 | 404 | 189 | 0 | | 415 | | 12 | | 0 | 55 |
| | | | OUT | -477 | 0 | 0 | 0 | -269 | -43 | -57 | | -25 | | 0 | | -41 | -7,502 |
| 18 | 2 | South of Tailings - Diversion Ditch | IN | 0 | 0 | 0 | 0 | | 147 | | 7,502 | | 1,049 | 3,615 | 0 | 3,379 | |
| | | | OUT | -2,500 | -2,560 | 0 | 0 | | 0 | | -55 | | -244 | -654 | -0 | -27 | |
| 29 | 3 | South of Tailings - Diversion Ditch | IN | 0 | 0 | 0 | 0 | | | | | | | 0 | | | 11,166 |
| | | | OUT | -2,601 | -11,043 | 0 | 0 | | | | | | | -31 | | | -921 |
| 39 | 4 | South of Tailings - Diversion Ditch | IN | 0 | 0 | 0 | 0 | | | | | | | | | | |
| | | | OUT | -3,090 | -18,569 | 0 | 0 | | | | | | | | | | |

| ZONE | LAYER | ZONE | | 19 East of Decant Pond Layer 2 | 23 Town Site Layer 3 | 24 Tailings Boundary NOT TAILINGS Layer 3 | 25 Decant Pond Layer 3 | 26 Kalin Canyon Layer 3 | 29 South of Tailings Incl Div Ditch Layer 3 | 30 East of Decant Pond Layer 3 | 33 Town Site Layer 4 | 34 Tailings Boundary NOT TAILINGS Layer 4 | 35 Decant Pond Layer 4 | 36 Kalin Canyon Layer 4 | 39 South of Tailings Incl Div Ditch Layer 4 | 40 East of Decant Pond Layer 4 | TOTAL |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 8 | 1 | South of Tailings - Diversion Ditch | IN | | | | | | | | | | | | | | -17,844 |
| | | | OUT | | | | | | | | | | | | | | -26,204 |
| 18 | 2 | South of Tailings - Diversion Ditch | IN | 610 | | | | | 921 | | | | | | | | -23,760 |
| | | | OUT | 0 | | | | | -11,166 | | | | | | | | -50,617 |
| 29 | 3 | South of Tailings - Diversion Ditch | IN | | 995 | 1,453 | 4 | 4,794 | | 653 | | | | | 1,504 | | -35,173 |
| | | | OUT | | -255 | -240 | 0 | -46 | | 0 | | | | | -5,558 | | -41,272 |
| 39 | 4 | South of Tailings - Diversion Ditch | IN | | | | | | 5,558 | | 2,290 | 11,875 | 5 | 5,082 | | 804 | -1,985 |
| | | | OUT | | | | | | -1,504 | | -249 | -2,050 | 0 | -54 | | 0 | -5,842 |

Table 12: East of Decant Pond

| ZONE | LAYER | ZONE | | Constant Head | Drains | River Leakage | Recharge | 4 Decant Pond Layer 1 | 8 South of Tailings Incl Div Ditch Layer 1 | 9 East of Decant Pond Layer 1 | 11 E.of Mud Lake-North of Decant Layer 1 | 14 Decant Pond Layer 2 | 18 South of Tailings Incl Div Ditch Layer 2 | 19 East of Decant Pond Layer 2 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 9 | 1 | East of Decant Pond | IN | 0 | 0 | 0 | 5,191 | 39 | 25 | | 12 | | | 0 |
| | | | OUT | 0 | 0 | 0 | 0 | -804 | -415 | | -158 | | | -3,890 |
| 19 | 2 | East of Decant Pond | IN | 0 | 0 | 0 | 0 | | | 3,890 | | 7 | 0 | |
| | | | OUT | 0 | 0 | 0 | 0 | | | 0 | | -8 | -610 | |
| 30 | 3 | East of Decant Pond | IN | 0 | 0 | 0 | 0 | | | | | | | 3,212 |
| | | | OUT | 0 | 0 | 0 | 0 | | | | | | | -106 |
| 40 | 4 | East of Decant Pond | IN | 0 | 0 | 0 | 0 | | | | | | | |
| | | | OUT | 0 | 0 | 0 | 0 | | | | | | | |

| ZONE | LAYER | ZONE | | 21 E.of Mud Lake-North of Decant Layer 2 | 25 Decant Pond Layer 3 | 29 South of Tailings Incl Div Ditch Layer 3 | 30 East of Decant Pond Layer 3 | 32 E.of Mud Lake-North of Decant Layer 3 | 35 Decant Pond Layer 4 | 39 South of Tailings Incl Div Ditch Layer 4 | 40 East of Decant Pond Layer 4 | 42 E.of Mud Lake-North of Decant Layer 4 | TOTAL |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 9 | 1 | East of Decant Pond | IN | | | | | | | | | | 8,072 |
| | | | OUT | | | | | | | | | | 2,805 |
| 19 | 2 | East of Decant Pond | IN | 0 | | | 106 | | | | | | 4,288 |
| | | | OUT | -173 | | | -3,212 | | | | | | -2,995 |
| 30 | 3 | East of Decant Pond | IN | | 62 | 0 | | 0 | | | 173 | | -2,751 |
| | | | OUT | | -368 | -653 | | -555 | | | -1,765 | | -6,093 |
| 40 | 4 | East of Decant Pond | IN | | | | 1,765 | | 314 | 0 | | 0 | -4,013 |
| | | | OUT | | | | -173 | | -520 | -804 | | -583 | -6,093 |

**Table 13: North of Tailings to Mud Lake**

| ZONE | LAYER | ZONE | | Constant Head | Drains | River Leakage | Recharge | 2 Tailings Boundary Tailings Layer 1 | 5 Kalin Canyon Layer 1 | 6 Mud Lake Layer 1 | 7 West of Kalin Canyon Layer 1 | 10 North of Tailings to Mud Lake Layer 1 | 11 E.of Mud Lake-North of Decant Layer 1 | 13 Tailings Boundary NOT TAILINGS Layer 2 | 15 Kalin Canyon Layer 2 | 16 Mud Lake Layer 2 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 10 | 1 | North of Tailings to Mud Lake | IN | 0 | 0 | 0 | 10,835 | 303 | 125 | 0 | 33 | | 484 | | 18 | |
| | | | OUT | 0 | 0 | 0 | 0 | -252 | -651 | -81 | -13 | | -313 | | -1,557 | |
| 20 | 2 | North of Tailings to Mud Lake | IN | 0 | 0 | 0 | 0 | | | | 61 | 8,933 | | 1,162 | 0 | 0 |
| | | | OUT | 0 | 0 | 0 | 0 | | | | 0 | -1 | | -128 | -32 | -7 |
| 31 | 3 | North of Tailings to Mud Lake | IN | 0 | 0 | 0 | 0 | | | | | | | | | |
| | | | OUT | 0 | 0 | 0 | 0 | | | | | | | | | |
| 41 | 4 | North of Tailings to Mud Lake | IN | 0 | 0 | 0 | 0 | | | | | | | | | |
| | | | OUT | 0 | 0 | 0 | 0 | | | | | | | | | |

| ZONE | LAYER | ZONE | | 20 North of Tailings to Mud Lake Layer 2 | 21 E.of Mud Lake-North of Decant Layer 2 | 24 Tailings Boundary NOT TAILINGS Layer 3 | 26 Kalin Canyon Layer 3 | 27 Mud Lake Layer 3 | 31 North of Tailings to Mud Lake Layer 3 | 32 E.of Mud Lake-North of Decant Layer 3 | 34 Tailings Boundary NOT TAILINGS Layer 4 | 36 Kalin Canyon Layer 4 | 37 Mud Lake Layer 4 | 41 North of Tailings to Mud Lake Layer 4 | 42 E.of Mud Lake-North of Decant Layer 4 | TOTAL |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 10 | 1 | North of Tailings to Mud Lake | IN | 1 | | | | | | | | | | | | 19,298 |
| | | | OUT | -8,933 | | | | | | | | | | | | -1,433 |
| 20 | 2 | North of Tailings to Mud Lake | IN | | 409 | | 0 | | 0 | | | | | | | 1,842 |
| | | | OUT | | -182 | | -2,902 | | -7,312 | | | | | | | -18,710 |
| 31 | 3 | North of Tailings to Mud Lake | IN | 7,312 | | 2,918 | 0 | 0 | | 1,086 | | | | 166 | | -7,066 |
| | | | OUT | 0 | | -411 | -4,931 | -646 | | -320 | | | | -5,173 | | -18,548 |
| 41 | 4 | North of Tailings to Mud Lake | IN | | | | | | 5,173 | | 2,930 | 0 | 0 | | 2,599 | -7,847 |
| | | | OUT | | | | | | -166 | | -446 | -5,432 | -3,399 | | -1,258 | -18,546 |

Table 14: East of Mud Lake, North of Decant Pond

| ZONE | LAYER | ZONE | | Constant Head | Drains | River Leakage | Recharge | 4 Decant Pond Layer 1 | 6 Mud Lake Layer 1 | 9 East of Decant Pond Layer 1 | 10 North of Tailings to Mud Lake Layer 1 | 11 E.of Mud Lake-North of Decant Layer 1 | 14 Decant Pond Layer 2 | 16 Mud Lake Layer 2 | 19 East of Decant Pond Layer 2 | 20 North of Tailings to Mud Lake Layer 2 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 11 | 1 | East of Mud Lake North of Decant | IN | 269 | 0 | 0 | 15,956 | 71 | 6 | 158 | 313 | | | | | |
| | | | OUT | -197 | 0 | -239 | 0 | -216 | -4,769 | -12 | -484 | | | | | |
| 21 | 2 | East of Mud Lake North of Decant | IN | 169 | 0 | 0 | 0 | | | | | 11,891 | 20 | 0 | 173 | 182 |
| | | | OUT | -332 | 0 | -192 | 0 | | | | | -1,036 | 0 | -2,076 | 0 | -409 |
| 32 | 3 | East of Mud Lake North of Decant | IN | 170 | 0 | 0 | 0 | | | | | | | | | |
| | | | OUT | -242 | 0 | -168 | 0 | | | | | | | | | |
| 42 | 4 | East of Mud Lake North of Decant | IN | 181 | 0 | 0 | 0 | | | | | | | | | |
| | | | OUT | -260 | 0 | -192 | 0 | | | | | | | | | |

| ZONE | LAYER | ZONE | | 21 E.of Mud Lake-North of Decant Layer 2 | 25 Decant Pond Layer 3 | 27 Mud Lake Layer 3 | 30 East of Decant Pond Layer 3 | 31 North of Tailings to Mud Lake Layer 3 | 32 E.of Mud Lake-North of Decant Layer 3 | 35 Decant Pond Layer 4 | 37 Mud Lake Layer 4 | 40 East of Decant Pond Layer 4 | 41 North of Tailings to Mud Lake Layer 4 | 42 E.of Mud Lake-North of Decant Layer 4 | TOTAL |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 11 | 1 | East of Mud Lake North of Decant | IN | 1,036 | | | | | | | | | | | 20,186 |
| | | | OUT | -11,891 | | | | | | | | | | | -8,478 |
| 21 | 2 | East of Mud Lake North of Decant | IN | | | | | | 1,215 | | | | | | -1,345 |
| | | | OUT | | | | | | -9,607 | | | | | | -23,032 |
| 32 | 3 | East of Mud Lake North of Decant | IN | 9,607 | 729 | 103 | 555 | 320 | | | | | | 1,645 | -6,438 |
| | | | OUT | -1,215 | -37 | -3,590 | 0 | -1,086 | | | | | | -6,791 | -19,327 |
| 42 | 4 | East of Mud Lake North of Decant | IN | | | | | | 6,791 | 913 | 205 | 583 | 1,258 | | -9,167 |
| | | | OUT | | | | | | -1,645 | -41 | -5,195 | 0 | -2,597 | | -18,826 |

Table 15: Mud Lake M60-A Groundwater Injection System Set-up.

| Injector No. | 25-Jul-00 ON w.l. (m) | 25-Jul-00 OFF w.l. (m) | Total Depth below collar (m) | 26-Jul-00 OFF w.l. (m) | 26-Jul-00 ON w.l. (m) |
|---|---|---|---|---|---|
| I-1 | 0.487 | 0.652 | 4.609 | 0.664 | 0.509 |
| I-2 | 0.485 | 0.638 | 4.652 | 0.656 | 0.5 |
| I-3 | 0.472 | 0.639 | 4.6 | 0.654 | 0.499 |
| I-4 | 0.473 | 0.632 | 3.642 | 0.654 | 0.494 |
| I-5 | 0.464 | 0.629 | 4.778 | | |
| I-6 | 0.462 | 0.631 | 4.778 | | |
| M60-A | 0.742 | 0.732 | | 0.735 | 0.762 |
| M60-B | 0.565 | 0.565 | | | |
| 26-Jul-00 | Total of 215 litres gravity fed to injectors in 10 minutes.<br>Therefore, flow was 0.35 $l.s^{-1}$<br>Water level in injectors were held at 0.48 m level using tank valve setting. | | | | |

Table 16a: Field Chemistry of Shallow Monitorining Piezometers Installed In the M60-A Injection Field, July, 2000.

| Piezometer | pH units | Temp ( C ) | Cond, uncorr. uS/cm | Em (mV) | |
|---|---|---|---|---|---|
| TN1 | 5.17 | 17.2 | 72 | 307 | |
| TN2 | 5.33 | 16.3 | 52 | 136 | |
| **TN3** | **6.07** | **14.6** | **130** | **74** | **Sampled** |
| TN4 | 5.69 | 15.6 | 92 | 77 | |
| TN5 | 5.58 | 15 | 78 | 108 | |
| TN6 | 5.77 | 14.2 | 97 | 93 | |
| TN7 | 5.70 | 14.7 | 80 | 115 | |
| TN8 | 5.92 | 14.4 | 110 | 127 | |
| TN9 | 5.90 | 14.6 | 105 | 146 | |
| TN10 | 6.11 | 15.6 | 130 | 115 | |
| TN11 | 5.98 | 16.6 | 118 | 57 | |
| TN12 | 6.20 | 14.1 | 121 | 138 | |
| **TN13** | **6.53** | **14.2** | **224** | **72** | **Sampled** |
| TN14 | 6.72 | 15.1 | 218 | 88 | |
| TN15 | 6.73 | 16.3 | 200 | 92 | |
| TN16 | 6.58 | 17.7 | 200 | 61 | |
| TN17 | 6.23 | 18.2 | 142 | 128 | |
| TN18 | 6.32 | 19 | 212 | 92 | |
| FT3 | 6.06 | 19.3 | 109 | 93 | TURBID SOUP! |
| FT4 | 6.20 | 11.8 | 145 | 121 | |
| FT5 | 6.11 | 13.2 | 139 | 142 | |
| FT6 | 6.08 | 13.7 | 121 | 170 | |
| FT7 | 5.88 | 13.5 | 90 | 195 | |
| FT8 | 6.21 | 15.9 | 155 | 170 | |

Table 16b: Assayer Results of Mud Lake Samples

| SAMPLE DATE | 28-Jul-00 | 28-Jul-00 | 27-Jul-00 | 27-Jul-00 | 28-Jul-00 | 28-Jul-00 |
|---|---|---|---|---|---|---|
| SAMPLE VOLUME | 15 | 15 | 15 | 15 | 15 | 15 |
| ASSAYERS CODE | 8691 | 8692 | 8687 | 8688 | 8689 | 8690 |
| SRC CODE | 17181 | 17182 | 17177 | 17178 | 17179 | 17180 |
| SAMPLING LOC. | South Bay | South Bay | South Bay | South Bay | South Bay | South Bay |
| | Mud Lake | Mud Lake | Mud Lake | Mud Lake | Mud Lake | Mud Lake |
| | TN3 | TN13 | ML18 | MML | M60A | M60B |
| | Injection | Injection | Outflow | Middle | Piezo | Piezo |
| | System | System | | Mud Lake | | |
| Processing code | FA | FA | FA | FA | FA | FA |
| ** F I E L D ** | | | | | | |
| Temp. (C) | 14.6 | 14.2 | 28.4 | 25.6 | 17.8 | 17.4 |
| pH | 6.07 | 6.53 | 2.62 | 2.61 | 6.05 | 7.11 |
| Cond. (umhos/cm) | 130 | 224 | 1660 | 1650 | 4025 | 460 |
| Eh (mV) | 322 | 320 | 703 | 735 | 156 | 188 |
| ** L A B ** | | | | | | |
| Temp. (C) | 18.5 | 18.7 | 18 | 18 | 17.9 | 18.4 |
| pH | 5.987 | 6.768 | 2.7 | 2.671 | 4.45 | 7.163 |
| Cond. (umhos/cm) | 158 | 256 | 1441 | 1522 | 3970 | 489 |
| Eh (mV) | 566 | 602 | 771 | 778 | 445 | 613 |
| Acidity (mg/l) | 39 | 18.3 | 356 | 418.4 | 2356.9 | 24.5 |
| Alkalinity (mg/l) | 71.9 | 112.7 | | | | 142.6 |
| Al | 0.11 | -0.005 | 0.86 | 0.064 | -0.005 | -0.005 |
| B | 0.007 | 0.009 | 0.012 | 0.011 | -0.002 | 0.015 |
| Ba | 0.071 | 0.087 | 0.026 | 0.023 | 0.033 | 0.097 |
| Ca | 26 | 46 | 110 | 100 | 440 | 98 |
| Cd | 0.01 | 0.012 | 0.011 | 0.012 | 0.06 | 0.006 |
| Co | -0.001 | -0.001 | 0.079 | 0.075 | 0.43 | -0.001 |
| Cr | 0.002 | 0.001 | 0.003 | 0.002 | -0.001 | 0.002 |
| Cu | 0.006 | 0.005 | 0.092 | 0.025 | -0.001 | 0.007 |
| Fe | 1.7 | 0.68 | 85 | 91 | 1310 | 1.6 |
| K | 1 | 1.9 | 4.1 | 5.2 | 20 | 4.1 |
| Mg | 2.3 | 3.7 | 21 | 21 | 91 | 7.1 |
| Mn | 0.12 | 0.17 | 7 | 7.1 | 31 | 0.7 |
| Mo | 0.005 | -0.001 | 0.006 | 0.002 | 0.002 | -0.001 |
| Na | 2 | 3.3 | 3.8 | 3.9 | 13 | 7 |
| Ni | 0.002 | -0.001 | 0.007 | 0.002 | 0.017 | -0.001 |
| P | 0.06 | 0.07 | 0.02 | -0.01 | 0.03 | -0.01 |
| Pb | -0.002 | -0.002 | 0.005 | -0.002 | 0.03 | -0.002 |
| S | 2.6 | 6.6 | 250 | 230 | 1240 | 34 |
| Si | 12 | 11 | 7.4 | 5.6 | 13 | 7.9 |
| Sr | 0.059 | 0.087 | 0.18 | 0.17 | 0.64 | 0.16 |
| Zn | 0.019 | 0.012 | 16 | 14 | 110 | 0.065 |

Table 17: Results of Surveying, July 2000 South Bay Site Visit.

| | | | | current | original | | |
|---|---|---|---|---|---|---|---|
| | | | | **23-Jul-00** | | Diff. | |
| 25-Jul-00 | Mud Lake w.l. is | 0.717 | m lower than Mud L.Landing benchmark | 413.99 | 413.61 | 0.38 | Airquest, Oct/86 |
| 25-Jul-00 | M58 collar is | 0.375 | m higher than Mud L.Landing benchmark | 415.08 | 415.01 | 0.07 | |
| 25-Jul-00 | M59 collar is | 0.718 | m higher than Mud L.Landing benchmark | 415.42 | 415.38 | 0.05 | |
| | | | | | | | |
| 25-Jul-00 | M60-A collar is | 0.381 | m higher than Mud L.Landing benchmark | 415.09 | 415.12 | -0.04 | |
| 25-Jul-00 | M60-B collar is | 0.184 | m higher than Mud L.Landing benchmark | 414.89 | 414.93 | -0.04 | |
| | | | | | | | |
| 25-Jul-00 | I-1 collar elevation is | 0.261 | m lower than M60 A collar | 414.83 | m.a.s.l. | | |
| 25-Jul-00 | I-2 collar elevation is | 0.273 | m lower than M60 A collar | 414.81 | m.a.s.l. | | |
| 25-Jul-00 | I-3 collar elevation is | 0.267 | m lower than M60 A collar | 414.82 | m.a.s.l. | | |
| 25-Jul-00 | I-4 collar elevation is | 0.267 | m lower than M60 A collar | 414.82 | m.a.s.l. | | |
| 25-Jul-00 | I-5 collar elevation is | 0.273 | m lower than M60 A collar | 414.81 | m.a.s.l. | | |
| 25-Jul-00 | I-6 collar elevation is | 0.273 | m lower than M60 A collar | 414.81 | m.a.s.l. | | |

## Table 18: Frequency of Water Level Measurements in Sand Pit Area

| 1997-98 | 21-Sep-97 | 20-Oct-97 | 26-Nov-97 | 16-Dec-97 | 18-Jan-98 | 28-Feb-98 | 26-Mar-98 | 26-Apr-98 | May | 4-Jun-98 | 31-Jul-98 | 31-Aug-98 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| M72C | 416.80 | 416.85 | 416.68 | 416.59 | 416.47 | 416.44 | 416.27 | 416.71 | | 416.73 | 416.67 | 416.58 |
| M87 | 416.83 | 417.02 | 416.83 | 416.75 | 416.52 | 416.52 | 416.3 | 416.91 | | | 416.69 | 416.6 |
| MSP4 | 417.00 | 417.07 | | | | | | 417.09 | | 417.16 | 417.04 | 417.05 |
| MSP5 | 416.78 | 416.94 | 416.74 | 416.70 | 416.59 | 416.49 | 416.25 | 416.7 | | 416.71 | 416.62 | 416.56 |
| MSP6 | 416.72 | 416.73 | | 416.53 | 416.35 | 416.4 | | 416.65 | | 416.67 | 416.71 | 416.53 |
| MSP8 | 416.83 | 417.05 | 416.84 | 416.73 | 416.70 | | | 416.94 | | 416.8 | 416.62 | |
| MSP9 | 416.76 | 416.92 | 416.72 | 416.62 | 416.40 | 416.47 | 416.26 | 416.64 | | 416.69 | 416.56 | 416.52 |
| MSP10 | 416.82 | 416.97 | 416.76 | 416.75 | 416.69 | 416.52 | 416.27 | 416.74 | | 416.75 | 416.67 | 416.6 |
| MSP11 | 416.81 | 416.94 | 416.74 | 416.67 | 416.45 | 416.51 | 416.28 | 416.71 | | 416.74 | 416.64 | 416.58 |
| MSP12 | 416.80 | 416.91 | 416.77 | 416.70 | 416.61 | 416.33 | 416.25 | 416.83 | | 416.73 | 416.65 | 416.56 |
| MSP13 | 416.84 | 416.93 | 416.73 | 416.65 | 416.45 | 416.49 | 416.28 | 416.75 | | 416.76 | 416.7 | 416.6 |
| MSU-A | | | | 416.69 | 416.48 | 416.51 | 416.31 | 416.73 | | 416.74 | 416.64 | 416.59 |
| MSU-B | | | | 416.71 | 416.34 | 416.42 | 416.3 | 416.77 | | 416.8 | 416.7 | 416.61 |

| 1998-99 | 25-Sep-98 | 25-Oct-98 | Nov | 8-Dec-98 | Jan | Feb | 12-Mar-99 | 21-Apr-99 | 22-May-99 | 27-Jun-99 | 23-Jul-99 | 27-Aug-99 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| M72C | 416.57 | 416.71 | | | | | 415.67 | 416.22 | | | 416.82 | |
| M87 | 416.55 | 416.74 | | | | | | 417.01 | | | 417.19 | |
| MSP4 | 417.05 | | | | | | | 417.13 | | 417.09 | 417.06 | |
| MSP5 | 416.54 | 416.71 | | 416.46 | | | | 416.99 | 416.49 | 416.56 | 416.87 | 416.32 |
| MSP6 | 416.51 | 416.57 | | 416.38 | | | | | | 416.41 | 416.68 | 416.32 |
| MSP8 | | 416.7 | | 416.41 | | | | 417.04 | 416.64 | 416.57 | 416.7 | |
| MSP9 | 416.54 | 416.69 | | 416.41 | | | | 416.47 | | 416.49 | 416.86 | 416.29 |
| MSP10 | 416.58 | 416.74 | | 416.49 | | | | 416.64 | 416.56 | 416.58 | 417.06 | 416.37 |
| MSP11 | 416.59 | 416.81 | | 416.48 | | | | | 416.51 | 416.58 | 416.74 | 416.37 |
| MSP12 | 416.55 | 416.71 | | 416.44 | | | 415.73 | 416.44 | 416.51 | 416.57 | 416.88 | 416.36 |
| MSP13 | 416.6 | 416.75 | | 416.47 | | | 415.76 | 416.35 | 416.52 | 416.58 | 416.94 | 416.39 |
| MSU-A | 416.6 | 416.76 | | 416.48 | | | 416.08 | 416.58 | 416.53 | 416.61 | 417.04 | 416.37 |
| MSU-B | 416.61 | 416.76 | | 416.48 | | | | 416.64 | 416.66 | 416.53 | 416.9 | 416.41 |

| 1999-00 | Sept | Oct | Nov | 7-Dec-99 | Jan | Feb | 10-Mar-00 | April | 11-May-00 | June | July | 2-Aug-00 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| M72C | | | | | | | 416.48 | | 416.72 | | | 416.57 |
| M87 | | | | | | | 416.46 | | 417.09 | | | 416.66 |
| MSP4 | | | | 416.98 | | | | | 417.09 | | | |
| MSP5 | | | | 416.54 | | | 416.4 | | 416.86 | | | 416.58 |
| MSP6 | | | | | | | | | 416.59 | | | 416.54 |
| MSP8 | | | | 416.82 | | | 416.56 | | 417 | | | 416.65 |
| MSP9 | | | | 416.52 | | | 416.39 | | 416.74 | | | 416.53 |
| MSP10 | | | | 416.58 | | | 416.47 | | 416.91 | | | 416.63 |
| MSP11 | | | | 416.75 | | | 416.61 | | 416.86 | | | 416.69 |
| MSP12 | | | | 416.56 | | | 416.58 | | 416.9 | | | 416.67 |
| MSP13 | | | | 416.69 | | | 416.58 | | 416.87 | | | 416.68 |
| MSU-A | | | | 416.58 | | | 416.52 | | 416.92 | | | 416.64 |
| MSU-B | | | | | | | | | 417.01 | | | 416.72 |

**Table 19: Data Collection Events**
**Water Samples with complete or partial chemical analysis**

| | 9/20/1997 | 10/21/1997 | 3/1/1998 | 6/7/1998 | 6/8/1998 | 8/30/1998 | 5/23/1999 | 6/27/1999 | 9/21/1999 | 12/7/1999 | 3/11/2000 | 5/12/2000 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| MSU-A | x | x | | x | | p | x | x | x | p | x | p |
| MSU-B | x | x | x | x | | p | x | x | x | | | p |
| MSP-1 | x | x | x | x | x | p | x | x | | p | x | p |
| MSP-4 | | x | | x | | p | | | | | | p |
| MSP-5 | x | x | x | x | x | p | | x | | p | x | |
| MSP-6 | x | x | x | x | x | p | | | | | | p |
| MSP-7 | x | x | x | x | x | p | | x | | p | x | p |
| MSP-8 | x | x | | x | x | | | | | | | p |
| MSP-9 | x | x | x | x | x | p | | x | | p | x | p |
| MSP-10 | x | x | x | x | x | | | x | | p | x | p |
| MSP-11 | x | x | x | x | x | p | x | x | x | p | x | p |
| MSP-12 | x | x | x | x | x | p | | x | | p | x | p |
| MSP-13 | x | x | x | x | x | p | x | x | x | p | x | p |
| DAYS AFTER ADDITION OF UREA | -1 | 30 | 161 | 259 | 260 | 343 | 609 | 644 | 730 | 807 | 902 | 964 |

**Nitrogen Concentration in Water Samples & Extracted Pore water from Sediment samples**
**Pore Water from Sediment Samples**

| | | 9/20/1997 | 10/21/1997 | 3/1/1998 | 6/7/1998 | 6/8/1998 | 8/30/1998 | 5/23/1999 | 6/27/1999 | 9/21/1999 | 12/7/1999 | 3/11/2000 | 5/12/2000 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Hole #7 | MSP-11 | | | | | | | | nm | | | | |
| Hole #8 | MSP-11 | | | | | | | | nm | | | | |
| Hole #11 | MSP-13 | | | | | | | | nm | | | | |
| Hole a | MSU-A 20cm N | | | | | | | | | x | | | |
| Hole b | MSU-A 200cm E | | | | | | | | | x | | | |
| Hole c | MSP-11 20cm SW | | | | | | | | | x | | | |
| Hole d | MSP-11 200cm S | | | | | | | | | x | | | |
| Hole e | MSP-13 200cm S | | | | | | | | | x | | | |
| Hole f | MSP-13 200cm SW | | | | | | | | | x | | | |
| Hole g | MSP-13 400cm SW | | | | | | | | | x | | | |
| Hole h | MSP-13 600cm SW | | | | | | | | | x | | | |
| Hole I | MSP-13 200cm N | | | | | | | | | x | | | |
| Hole halfway between MSP-11 & M72A | | | | | | | | | | | x | | |
| Hole halfway between MSP-13 & M72A | | | | | | | | | | | x | | |
| Hole halfway between MSP-13 & M72A | | | | | | | | | | | x | | |
| Hole halfway between MSU-A $ MSP-11 | | | | | | | | | | | x | | |
| DAYS AFTER ADDITION OF UREA | | -1 | 30 | 161 | 259 | 260 | 343 | 609 | 644 | 730 | 807 | 902 | 964 |

**Water Samples from Piezometers**

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| MSP-1 | | | | | | | | x | | x | | |
| MSP-5 | | | | | | | | x | | x | | |
| MSP-7 | | | | | | | | x | | x | | |
| MSP-9 | | | | | | | | x | | x | | |
| MSP-10 | | | | | | | | x | | x | | |
| MSP-11 | | | | | x | x | x | x | | x | x | |
| MSP-12 | | | | | | | | x | | x | | |
| MSP-13 | | | | | x | x | x | x | | x | x | |
| MSU-A | | | | | | | | x | | x | | |
| MSU-B | | | | | | | | x | | | | |

**Table 20a: Comparison of Water Cheimstry Before and After Urea / Sugar Added to Sand Pit**

| MSP9 | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 9/12/97 | 10/21/97 | 3/1/98 | 6/7/98 | 6/8/98 | 8/30/98 | 6/27/99 | 12/7/99 | 9/14/00 |
| 19.2 | | | 15 | 18 | 13 | 14.7 | | |
| 4.48 | | | 5.53 | 5.12 | 3.46 | 5.39 | | |
| 403 | | | 40 | 42 | 450 | | | |
| 459 | | | 432.6 | 415.62 | 562 | MP | | |
| 25 | 15.2 | 14.9 | 19.8 | 17.2 | 9 | 18.5 | 9.7 | 21.2 |
| 2.54 | 3.71 | 5 | 5.11 | 4.5 | 3.55 | 4.95 | 5.5 | 4.19 |
| 510 | 262 | 52.5 | 50 | 58.5 | 538 | 39 | 35 | 78.4 |
| 545 | 708 | 485 | 429.43 | 417.15 | 620 | MP | 505 | 561 |
| 174.4 | 98.1 | 22.6 | 10.6 | 12.1 | 158.9 | 15 | 17 | 24 |
| | | 2.1 | 2.4 | 1.8 | | 4.3 | 5.1 | |
| 3.21 | 2 | 0.16 | 0.17 | 0.15 | | 0.13 | 29 | 0.44 |
| 17.5 | 6.5 | 2.8 | 2.8 | 2.9 | | 2.6 | 4 | 3.5 |
| 0.066 | 0.018 | 0.006 | 0.01 | 0.01 | | 0.015 | <0.01 | 0.009 |
| 0.15 | 0.028 | 0.004 | 0 | 0.01 | | 0.002 | <0.01 | 0.008 |
| 0.03 | 0.038 | 0.027 | 0.01 | 0.01 | | 0.01 | 0.05 | 0.066 |
| 21 | 0.91 | 0.27 | 1.7 | 2.2 | | 0.062 | 25 | 0.56 |
| 2.83 | 0.9 | 0.5 | 0.9 | 0.8 | | 0.8 | 5 | 1 |
| 5.95 | 2.1 | 0.83 | 0.8 | 0.8 | | 0.7 | 6 | 1.1 |
| 3.48 | 0.65 | 0.074 | 0.08 | 0.1 | | 0.049 | 0.21 | 0.18 |
| 1.53 | 1.9 | 0.9 | 1.3 | 1.4 | | 1.1 | <5 | 1.7 |
| -0.05 | 0.01 | 0.003 | -0.001 | 0 | | 0.005 | 0.04 | 0.004 |
| -0.02 | -0.05 | -0.05 | 0.09 | -0.05 | | -0.01 | 0.2 | <0.01 |
| -0.04 | -0.002 | | -0.002 | -0.002 | | -0.002 | <0.02 | 0.006 |
| 49.7 | 24 | 5.3 | 6 | 6.3 | | 4.5 | nm | 7.4 |
| | 7.4 | 4.6 | 6.1 | 6 | | 6.1 | 65 | 6 |
| 0.11 | 0.059 | 0.036 | 0.03 | 0.03 | | 0.029 | 0.05 | 0.028 |
| -0.02 | -0.001 | | -0.001 | -0.001 | | -0.001 | 0.97 | <0.001 |
| 38.5 | 14 | 2.7 | 2.2 | 2.2 | | 3.2 | 1.8 | 2.1 |
| | -0.001 | | -0.001 | -0.001 | | -0.001 | 0.01 | <0.001 |
| | | | | | | 0.06 | 0.17 | <0.05 |
| | | | | | | 0.39 | 0.4 | <0.01 |
| | | | | | | -0.05 | 0.83 | 1 |

Note : The Date of Urea added to Sand Pit was Sept. 21, 1997, first sugar addition was Oct. 4, 1999 and second was May 12, 2000.

**Table 20b: Comparison of Water Cheimstry Before and After Urea / Sugar Added to Sand Pit**

| MSP11 | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 9/21/97 | 10/21/97 | 3/1/98 | 6/7/98 | 6/8/98 | 8/30/98 | 5/23/99 | 6/27/99 | 9/21/99 | 12/7/99 | 3/11/00 | 9/14/00 |
| 17.3 | | | 17 | 17 | 14 | | 15 | | | | |
| 3.97 | | | 3.23 | 4.23 | 3.52 | | 4.23 | | | | |
| 3880 | | | 2800 | 4250 | 3400 | | | | | | |
| 436 | | | 568.28 | 432.28 | 519 | | MP | | | | |
| 22.5 | 15.3 | 14.8 | 20.6 | 17.5 | 10 | 11.1 | 19 | 12 | 10 | | 20.7 |
| 3.59 | 4.04 | 3.84 | 3.57 | 3.42 | 3.53 | 3.8 | 3.6 | 3.54 | 3.61 | | 3.389 |
| 10790 | 6900 | 5410 | 3920 | 3400 | 5600 | 3460 | 4400 | 4560 | 2920 | | 3180 |
| 208 | 435 | 530 | 513.9 | 532.95 | 544 | 509 | MP | 556 | 538 | | 513 |
| 8217 | 6378.8 | 4013.2 | 2646.5 | 3540.8 | 4955.9 | 2503 | 3898 | 3718 | 1943.9 | | 3181.8 |
| | | | | | | | | | | | |
| 229 | 240 | 120 | 55 | 110 | | 66 | 100 | 120 | 79 | | 50 |
| 367 | 330 | 160 | 92 | 160 | | 110 | 160 | 180 | 90 | | 100 |
| 1.26 | 1.1 | 0.62 | 0.34 | 0.55 | | 0.31 | 0.59 | 0.58 | 0.28 | | 0.32 |
| 4.27 | 3.3 | 1.8 | 1.1 | 1.8 | | 1.2 | 1.7 | 1.8 | 1 | | 1.1 |
| 9.8 | 5.4 | 3 | 1.8 | 3.4 | | 2 | 3.4 | 3.3 | 1.7 | | 3.4 |
| 5950 | 4500 | 1620 | 910 | 1990 | | 1060 | 1670 | 1780 | 920 | | 1040 |
| 9.47 | 12 | 11 | 13 | 12 | | 11 | 16 | 16 | 12 | | 12 |
| 222 | 170 | 73 | 40 | 67 | | 44 | 78 | 85 | 47 | | 42 |
| 143 | 100 | 40 | 26 | 41 | | 27 | 50 | 48 | 26 | | 25 |
| 3.31 | 55 | 36 | 13 | 23 | | 4.2 | 5.3 | 5.5 | <25 | | 4.5 |
| 0.51 | 0.41 | 0.25 | 0.15 | 0.24 | | 0.16 | 0.24 | 0.28 | 0.18 | | 0.17 |
| 1.88 | 0.13 | 0.05 | 0.07 | 0.09 | | 0.05 | 0.04 | 0.03 | <0.5 | | 0.02 |
| 0.27 | 0.12 | | 0.05 | 0.06 | | 0.033 | 0.079 | 0.069 | <0.1 | | 0.04 |
| 4270 | 4060 | 1650 | 850 | 1670 | | 1010 | 1620 | 1750 | nm | | 940 |
| | 22 | 19 | 17 | 19 | | 15 | 20 | 22 | 82 | | 20 |
| 0.39 | 0.35 | 0.32 | 0.22 | 0.28 | | 0.2 | 0.29 | 0.32 | 0.28 | | 0.19 |
| 0.13 | 0.002 | | 0 | 0 | | -0.001 | -0.001 | -0.001 | 1.5 | | 0.002 |
| 968 | 680 | 310 | 180 | 340 | | 200 | 320 | 310 | 160 | | 180 |
| | 0.067 | | 0.02 | 0.04 | | 0.024 | 0.039 | 0.042 | <0.05 | | 0.018 |
| | | | | | 15 | 17 | 9.3 | | 20 | 32 | 12 |
| | | | | | -0.05 | 0.54 | -0.01 | | 0.11 | <0.1 | <0.05 |
| | | | | | 334 | 2140 | 1630 | | 1050 | 330 | 79 |

Note : The Date of Urea added to Sand Pit was Sept. 21, 1997, first sugar addition was Oct. 4, 1999 and second was May 12, 2000.

**Table 20c: Comparison of Water Cheimstry Before and After Urea / Sugar Added to Sand Pit**

| Element (mg/l) | MSP13 | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 9/21/97 | 10/21/97 | 3/1/98 | 6/7/98 | 6/8/98 | 8/30/98 | 5/23/99 | 6/27/99 | 9/21/99 | 12/7/99 | 3/11/00 | 9/14/00 |
| F*Temp (°C) | 17.2 | | | 17 | 17 | 15 | | 15.5 | | | | |
| F*pH | 4.11 | | | 3.68 | 4.13 | 3.76 | | 4.18 | | | | |
| F*Cond (us/cm) | 6440 | | | 7000 | 7800 | 5500 | | | | | | |
| F*Eh (mv) | 374 | | | 481.28 | 421.28 | 481 | | MP | 280 | | | |
| L*Temp (°C) | 22.6 | 15.2 | 15.9 | 20.6 | 17.6 | 9.8 | 11.7 | 19.5 | 13.9 | 10.4 | | 20.7 |
| L*pH | 3.46 | 4.06 | 4.04 | 3.81 | 3.94 | 3.79 | 4.12 | 3.83 | 3.53 | 3.89 | | 3.368 |
| L*Cond (us/cm) | 12870 | 8420 | 9630 | 8350 | 6900 | 6930 | 7740 | 6800 | 6550 | 7240 | | 7990 |
| L*Eh (mv) | 209 | 421 | 454 | 466.9 | 451.88 | 505 | 447 | MP | 528 | 489 | | 464 |
| L*Acid | 17420 | 17825 | 6986.7 | 8795 | 9854 | 6323.6 | 6967.1 | 6496.5 | 5735.4 | 6233.9 | | 8262.3 |
| L*Alk. | | | | | | | | | | | | |
| Al | 132 | 200 | 210 | 210 | 210 | | 170 | 150 | 150 | 110 | | 110 |
| Ca | 386 | 450 | 340 | 310 | 350 | | 310 | 320 | 350 | 300 | | 340 |
| Cd | 1.06 | 1.1 | 1.2 | 1 | 1.1 | | 0.88 | 0.98 | 0.79 | 0.82 | | 0.9 |
| Co | 4.8 | 4 | 3.4 | 3.2 | 3.7 | | 3.1 | 2.8 | 2.4 | 3.1 | | 3.1 |
| Cu | 5.96 | 5.1 | 6.5 | 7.3 | 6.5 | | 4.8 | 5.4 | 4.9 | 3.9 | | 4.7 |
| Fe | 7270 | 6550 | 4120 | 3860 | 4830 | | 3530 | 3360 | 2910 | 3450 | | 3820 |
| K | 8.26 | 11 | 12 | 14 | 14 | | 10 | 17 | 17 | 13 | | 17 |
| Mg | 240 | 240 | 160 | 140 | 170 | | 130 | 130 | 130 | 120 | | 100 |
| Mn | 171 | 160 | 57 | 83 | 110 | | 83 | 85 | 80 | 76 | | 96 |
| Na | 4.28 | 91 | 64 | 24 | 27 | | 17 | 7.7 | 6.6 | 7 | | 7.2 |
| Ni | 0.39 | 0.34 | 0.37 | 0.41 | 0.41 | | 0.39 | 0.36 | 0.32 | 0.38 | | 0.28 |
| P | 2.46 | 0.1 | 0.1 | 0.09 | 0.12 | | 0.1 | 0.05 | 0.04 | 0.1 | | 0.05 |
| Pb | 0.32 | 0.15 | | 0.11 | 0.14 | | 0.084 | 0.14 | 0.099 | <0.02 | | 0.12 |
| S | 5000 | 5560 | 3640 | 3020 | 3840 | | 2970 | 3010 | 2740 | nm | | 3270 |
| Si | | 24 | 26 | 28 | 26 | | 23 | 32 | 27 | 28 | | 26 |
| Sr | 0.3 | 0.24 | 0.27 | 0.23 | 0.25 | | 0.22 | 0.27 | 0.25 | 0.28 | | 0.27 |
| Ti | 0.16 | 0.002 | | 0.01 | 0.01 | | -0.001 | -0.001 | -0.001 | 0.01 | | 0.002 |
| Zn | 1210 | 1110 | 640 | 540 | 730 | | 540 | 550 | 530 | 600 | | 680 |
| Zr | | 0.085 | | 0.07 | 0.08 | | 0.073 | 0.071 | 0.068 | 0.03 | | 0.073 |
| Ammonia as N | | | | | | 18 | 20 | 15 | | 41 | 33 | 35 |
| Nitrate as N | | | | | | -0.05 | -0.05 | -0.01 | | -0.01 | <0.1 | <0.25 |
| TKN | | | | | | 513 | 2130 | 2230 | | 1070 | 500 | 32 |

Note : The Date of Urea added to Sand Pit was Sept. 21, 1997, first sugar addition was Oct. 4, 1999 and second was May 12, 2000.

## Table 21: Nitrogen Concentration in Water and Solids at Sand Pit

**Water**

| Nutrients (SRC) (mg/l) | MSU-A | | MSP13 | | | | | MSP11 | | | | | MSP9 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 6/27/99 | 12/7/99 | 8/30/98 | 5/23/99 | 6/27/99 | 12/7/99 | 3/11/00 | 8/30/98 | 5/23/99 | 6/27/99 | 12/7/99 | 3/11/00 | 6/27/99 | 12/7/99 |
| | After Urea and before carbon | After Urea and Carbon | After Urea and before carbon | | | After Urea and Carbon | | After Urea and before carbon | | | After Urea and Carbon | | Before urea and carbon | |
| $NH_3$ as N | 5.5 | 0.13 | 18 | 20 | 15 | 41 | 33 | 15 | 17 | 9.3 | 20 | 32 | 0.06 | 0.17 |
| $NO_3$ as N | 2.5 | 1.3 | <0.05 | <0.05 | <0.01 | <0.01 | <0.1 | <0.05 | 0.54 | <0.01 | 0.11 | <0.1 | 0.39 | 0.4 |
| TKN | 9 | 1.1 | 513 | 2130 | 2230 | 1070 | 500 | 334 | 2140 | 1630 | 1050 | 330 | <0.05 | 0.83 |
| Urea (converted) | 19 | 2 | 1099 | 4564 | 4779 | 2293 | 1071 | 716 | 4586 | 3493 | 2250 | 707 | 0.11 | 1.78 |

**Solid**

| Nutrients (SRC) (ug/g) | MSU - A | | MSP 13 | | | | | | | MSP11 | | | | | | | MSP 9 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 20cm N a | 2m E (between MSP11 & MSU-A) b | 0.5m N (between MSP13 & MSU-B) 11 | 2m S (between MSP13 & M72A) e | 2m W (between MSP11 & MSP13) f | 4mW (between MSP11 & MSP13) g | 2m N (between MSP13 & MSU-B) i | between MSP13 & MSU-B | between MSP13 & M72A | 0.5m W (between MSP11 & MSU-A) 7 | 1m E (between MSP11 & MSP13) 8 | 20cm SW c | 2m S d | 2m E (between MSP11 & MSP13) h | between MSP11 & MSU-A | between MSP11 & M72A | 25 cm | 65cm | 85 cm |
| | 9/21/99 | 9/21/99 | 6/27/99 | 9/21/99 | 9/21/99 | 9/21/99 | 9/21/99 | 12/7/99 | 12/7/99 | 6/27/99 | 6/27/99 | 9/21/99 | 9/21/99 | 9/21/99 | 12/7/99 | 12/7/99 | 9/9/97 | 9/9/97 | 9/9/97 |
| | After Urea and Before Carbon | | After Urea and before carbon | | | | | After urea and carbon | | After Urea and before carbon | | | | | After Urea and Carbon | | Before urea and carbon | | |
| Moisture % | 18.5 | 13.3 | nm | 18.5 | 15.5 | 11 | 16.5 | 18.0 | 22.3 | nm | nm | 13.0 | 13.0 | 12.5 | 15.0 | 18.7 | nm | nm | nm |
| $NH_3$ as N | 10 | 14 | nm | 22 | 35 | 34 | 18 | 17 | 23 | nm | nm | 37 | 31 | 31 | <5 | 27 | 3.27 (Boojum) | 3.84 (Boojum) | 3.06 (Boojum) |
| $NO_3$ as N | 8 | 10 | nm | <1 | <1 | <1 | 1 | 3 | <1 | nm | nm | <1 | 4 | <1 | 6 | 2 | nm | nm | nm |
| TKN | 49 | 200 | nm | 280 | 180 | 440 | 220 | 88 | 140 | nm | nm | 160 | 150 | 260 | 100 | 120 | nm | nm | nm |
| Urea-solid (converted) | 105 | 429 | nm | 600 | 386 | 943 | 471 | 189 | 300 | nm | nm | 343 | 321 | 557 | 214 | 257 | nm | nm | nm |
| TKN-solid converted to TKN-porewater | 216 | 1309 | nm | 1234 | 981 | 3560 | 1113 | 401 | 488 | nm | nm | 1071 | 1004 | 1820 | 567 | 522 | nm | nm | nm |
| Urea-porewater (converted) | 463 | 2806 | nm | 2643 | 2103 | 7629 | 2386 | 859 | 1045 | nm | nm | 2295 | 2151 | 3900 | 1214 | 1118 | nm | nm | nm |

**Table 22: Chemistry of Water Collected after Bailing from Sandpit Piezometers 8-Oct-00**

unit:mg/l

| Piezo # | pH | Eh (mv) | Cond 25$^{o}$C(us/cm) | Acidity | $NH_4$-N | $NO_3$-N | TKN |
|---|---|---|---|---|---|---|---|
| MSP-1 | 3.05 | 527 | 6733 | 4896.4 | 5.6 | 3.3 | 6.6 |
| MSP-3 | 6.41 | 411 | 44 | 8.6 | 0.1 | <0.01 | 1.7 |
| MSP-5 | 4.92 | 456 | 116 | 30.9 | 0.06 | 0.07 | 1.5 |
| MSP-6 | 3.01 | 560 | 12903 | 17167.6 | not in | 10 | not in |
| MSP-7 | 4.303 | 522 | 1316 | 74.6 | <0.05 | <0.01 | 2.1 |
| MSP-8 | 6.335 | 463 | 45 | 14.7 | 0.14 | <0.01 | 1.8 |
| MSP-9 | 5.715 | 465 | 32 | 15.4 | 0.06 | 0.04 | 3.7 |
| MSP-10 | 5.749 | 455 | 50 | 14.7 | 0.08 | 0.09 | 1.8 |
| MSP-11 | 3.407 | 563 | 4050 | 2591.8 | 5.6 | 0.6 | 89 |
| MSP-12 | 3.481 | 509 | 9077 | 30353.9 | 7.4 | <0.1 | 8.3 |
| MSP-13 | 3.571 | 497 | 9471 | 8738.2 | 9 | <0.2 | 36 |
| MSU-A | 5.647 | 436 | 44 | 16.1 | 0.1 | 0.17 | 1.6 |
| MAU-B | 3.519 | 506 | 8016 | 9300 | 5.4 | 2 | 5.6 |

**Table 23: Set up of Biomagic Tube Experiment Using MSP-11 Water and MSU-B Sediment**

| Tube # | Incubation °C | Urea (mg/l) | Sugar (mg/l) | Yeast Extract (mg/l) | Micro Inoculum (ul) | Sediment |
|---|---|---|---|---|---|---|
| 1 | 22 | 2500 | 500 | 50 | 100 | Yes |
| 2 - 8 | 5 | 2500 | 500 | 50 | 100 | Yes |
| 9 - 12 | 22 | 2500 | 500 | 50 | 100 | Yes |
| 13 - 14 | 22 | 2500 | - | - | 100 | Yes |
| 15 | 5 | 2500 | - | - | 100 | Yes |
| 16 | 5 | 2500 | - | - | 100 | No |
| 17 | 5 | 2500 | 500 | 50 | 100 | No |

**Table 24a: pH of Top Water for Biomagic Test Using MSU-B Sediment and MSP-11 Water**

| tube # | incubated Temp $^oC$ | Sediment | Materials added to sediment | pH | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | 0 d (corning) | 40 d (color Phast) | 67 d (color Phast) | 98 d (color Phast) | 104 d (corning) | 308 d ** (corning) |
| 2 | 5 | Yes | Urea + sugar + yeast extract | 3.73 | 4.5 | 4.5 | 4.5 | nm | 5.67 |
| 3 | | Yes | | 3.73 | 4.5 | 4.5 | 4.5 | 4.65 | 3.97 |
| 4 | | Yes | | 3.73 | 4.5 | 4.5 | 4.5 | nm | 5.06 |
| 5 | | Yes | | 3.73 | 4.5 | 4.5 | 4.5 | nm | 4.82 |
| 6 | | Yes | | 3.73 | 4.5 | 4.5 | 5.0 | 5.29 | 3.74 |
| 7 | | Yes | | 3.73 | 4.5 | 4.5 | 4.5 | nm | 4.80 |
| 8 | | Yes | | 3.73 | 4.5 | 4.5 | 5.0 | nm | 6.21 |
| 1 | 22 | Yes | | 3.73 | 3.0 | 3.0 | 3.8 | nm | no more sample |
| 9 | | Yes | | 3.73 | 6.0 | 6.0 | 6.5 | 6.17 | 4.54 |
| 10 | | Yes | | 3.73 | 6.0 | 6.5 | 7.0 | nm | 6.12 |
| 11 | | Yes | | 3.73 | 6.0 | 6.5 | 6.5 | nm | 5.97 |
| 12* | | Yes | | 3.73 | 5.0 | 3.0 | 2.7 | 2.85 | no top water |
| 13 | | Yes | Urea only | 3.73 | 4.0 | 4.0 | 4.0 | nm | 3.84 |
| 14 | | Yes | | 3.73 | 4.0 | 4.0 | 4.0 | nm | 3.87 |
| 15 | | Yes | | 3.73 | 4.0 | 4.0 | 4.0 | 3.74 | 3.53 |
| 16 | 5 | NO | | 3.73 | 3.0 | 3.0 | 3.0 | 3.74 | 2.96 |
| 17 | | NO | Urea + sugar + yeast extract | 3.73 | 3.5 | 3.5 | 4.0 | 3.48 | 3.24 |

nm: not measured. * Tube 12 was exposured to air after 40 days.

** Tube 9 has only 0.2cm water layer on top of sediment, and all other tubes have 5 cm.

Table 24b: Chemistry of Top Water for Biomagic Tube Expt Using MSU-B Sediment and MSP-11 Water after Incubating for 104 Days

| Additive (mg/L) | Sample | incubated Temp $^{o}$C | Corning pH | color Phast pH | Eh (mv) | Cond (us/cm) | Acidity (mg/L) | Glucose (mg/L) | Sugar (mg/l) | Sugar Consumed (mg/l) | Sugar Consumed (mg/d) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| none | MSP-11 after bailing | 22 | 2.70 | 2.50 | 704 | 4280 | 4920.5 | 1.99 | 1.23 | | |
| | MSU-B +DH2O slurry | 22 | 4.03 | 4.50 | 530 | 198 | 54.6 | 0 | -1.46 | | |
| | MSP 11 + MSU-B Slurry | 22 | 2.61 | 2.50 | 698 | 3940 | 4301 | na | na | | |
| sugar +urea +yeast | tube #3 | 5 | 4.65 | 4.50 | 346 | 3960 | 2373.2 | 12.14 | 14.97 | 485.03 | 4.37 |
| | tube #6 | 5 | 5.29 | 6.00 | 243 | 4120 | 2535.5 | 7.88 | 9.21 | 490.79 | 4.42 |
| | tube #9 | 22 | 6.17 | 7.00 | 116 | 5400 | 2211.2 | 6.77 | 7.70 | 492.30 | 4.44 |
| | tube #12* | 22 | 2.85 | 3.00 | 645 | 2100 | 2284.1 | 26.17 | 33.97 | 466.03 | 4.20 |
| | tube #17 (MSP 11 Water only) | 5 | 3.48 | 3.50 | 467 | 4910 | 4087.7 | 54.55 | 72.40 | 427.60 | 3.85 |
| | MSU-B + MSP 11 slurry | 22 | 2.37 | 2.50 | 713 | 3830 | 3971.6 | na | na | na | na |
| urea only | tube #15 (MSU-B + MSP 11) | 22 | 3.74 | 4.00 | 467 | 3810 | 3109.6 | 3.8 | 3.68 | | |
| | tube #16 (MSP-11 water only) | 5 | 3.74 | 3.00 | 539 | 5030 | 4170 | 4.91 | 5.18 | | |
| | MSU-B + MSP 11 slurry | 22 | 2.55 | 2.50 | 715 | 3770 | 4014.1 | na | na | na | na |

na =  interference occurred due to high acidity.
* tube 12 was under aerobic condition.

**Table 25 : Ratio of Sugar to Urea in Sand Pit, 27-July-00**

| Location | Yeast Extract Added (mg/l) | Sugar Added (mg/l) | Urea (mg/l) | Sugar / Urea | Urea (mg/l) | Time Period of Sugar Consumed (day) | Urea Consumed (mg/l) | Urea Consumed (mg/day) |
|---|---|---|---|---|---|---|---|---|
| **Bakground (No Sugar and Yeast Extract)** | | | | | | | | |
| | 1-Jun-99 | | 23-May-99 | ratio | 27-Jun-99 | from 23-May-99 to 27-Jun-99 | | |
| MSP-11 | none | none | 4586 | 0 | 3493 | 35 | 1093 | 31.2 |
| MSP-13 | none | none | 4564 | 0 | 4779 | 35 | -214 | -6.1 |
| **First Sugar (2.5 kg/hole) and Yeast Extract (0.25 kg/hole) 4-Oct-99** | | | | | | | | |
| | 4-Oct-99 | | 27-Jun-99 | ratio | 11-Mar-00 | from 27-Jun-99 to 11-Mar-00 | | |
| MSP11 | 769 | 7692 | 3493 | 2.2 | 707 | 258 | 2786 | 10.8 |
| MSP13 | 769 | 7692 | 4779 | 1.6 | 1071 | 258 | 3707 | 14.4 |
| **Second Sugar Only (5 kg/hole) 27-Jul-00** | | | | | | | | |
| | 27-Jul-00 | | 11-Mar-00 | ratio | 14-Sep-00 | from 11-Mar-00 to 14-Sep-00 | | |
| MSP11 | none | 15385 | 707 | 21.8 | 169 | 187 | 538 | 3 |
| MSP13 | none | 15385 | 1071 | 14.4 | 69 | 187 | 1003 | 5 |
| **Continued (Second Sugar Only, 27-Jul-00)** | | | | | | | | |
| | 27-Jul-00 | | 14-Sep-00 | ratio | 8-Oct-00 | from 14-Sep-00 to 8-Oct-00 | | |
| MSP11 | none | 15385 | 169 | 90.9 | 191 | 24 | -21 | -0.11 |
| MSP13 | none | 15385 | 69 | 224.4 | 77 | 24 | -9 | -0.05 |

**Table 26: Set up of Urea/Sugar/Yeast Extract Experiment at Sand Pit in South Bay**

| Location of Circle | Treatment | Amendment Addition (kg/circle) | | | Ratio of Urea : Sugar : Yeast Extract |
|---|---|---|---|---|---|
| | | Urea | Sugar | Yeast Extract | |
| Around MSP-12 (North of MSP-12) | Urea only | 11 | 0 | 0 | 1 : 0 : 0 |
| Around MSP-13 (North of MSP-13) | Urea+Sugar+Yeast Extract | 11 | 22 | 0.22 | 1 : 2 : 0.02 |
| Between MSP-11 & MSU-A | Urea+Sugar | 11 | 22 | 0 | 1 : 2 : 0 |

Table 27: Calculation of Urea Concentration

| | | TRAPEZOID | CIRCLE (r=2m) |
|---|---|---|---|
| Urea applied | kg | 350 | 12 |
| Area | m2 | 116.5 | 12.6 |
| Average thickness | m | 1 | 1 |
| Volume | m3 | 116.5 | 12.6 |
| Volume of water (20%) | m3 | 23.3 | 2.52 |
| Urea concentration WITHOUT DILUTION | mg/L | 15021 | 4762 |
| TKN concentration (factor=2.1431) WITHOUT DILUTION | mg/L | 7009 | 2222 |
| Precipitation (Sep 97 - Jun 00) | mm | 1262 | |
| Net precipitation (1/3) | mm | 421 | |
| Precipitation on calculated area | m3 | 49.0 | |
| Urea concentration WITH DILUTION | mg/L | 4840 | |
| TKN concentration (factor=2.1431) WITH DILUTION | mg/L | 2259 | |
| 1 month after | mg/L | | 2091 |
| 2 month after | mg/L | | 1968 |
| 3 month after | mg/L | | 1874 |
| 4 month after | mg/L | | 1823 |
| 5 month after | mg/L | | 1774 |
| 6 month after | mg/L | | 1701 |
| 7 month after | mg/L | | 1585 |
| 8 month after | mg/L | | 1431 |
| 9 month after | mg/L | | 1279 |
| 10 month after | mg/L | | 1190 |
| 11 month after | mg/L | | 1096 |
| 12 month after | mg/L | | 1042 |

| AVERAGE PRECIPITATION | | | |
|---|---|---|---|
| | 10years | 1/3 net | cumul |
| November | 37.52 | 12.51 | 12.51 |
| December | 40.02 | 13.34 | 25.85 |
| January | 33.97 | 11.32 | 37.17 |
| February | 19.71 | 6.57 | 43.74 |
| March | 20.4 | 6.80 | 50.54 |
| April | 32.09 | 10.70 | 61.24 |
| May | 57.42 | 19.14 | 80.38 |
| June | 90.82 | 30.27 | 110.65 |
| July | 110.26 | 36.75 | 147.40 |
| August | 78.05 | 26.02 | 173.42 |
| September | 96.05 | 32.02 | 205.44 |
| October | 63.31 | 21.10 | 226.54 |

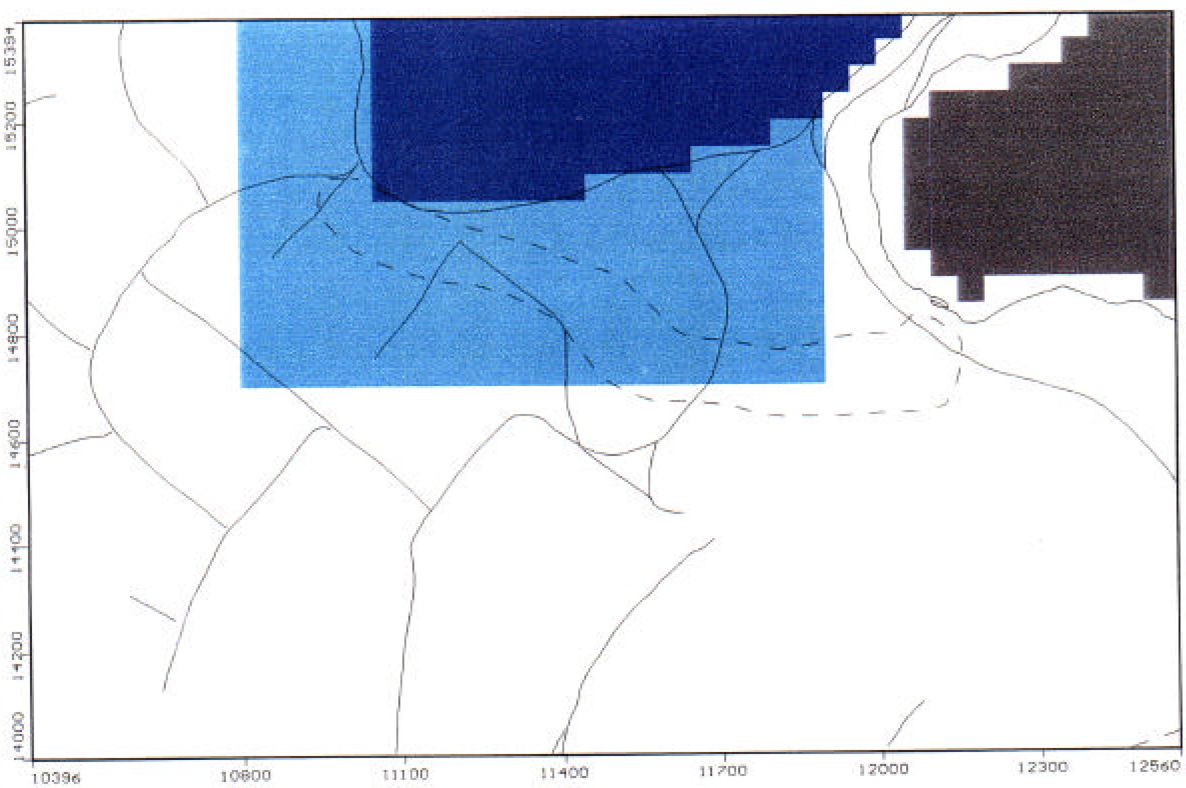



Figure 1: Hydraulic Conductivity, South of Tailings, Layer 1


Figure 2: Hydraulic Conductivity, South of Tailings, Layer 2

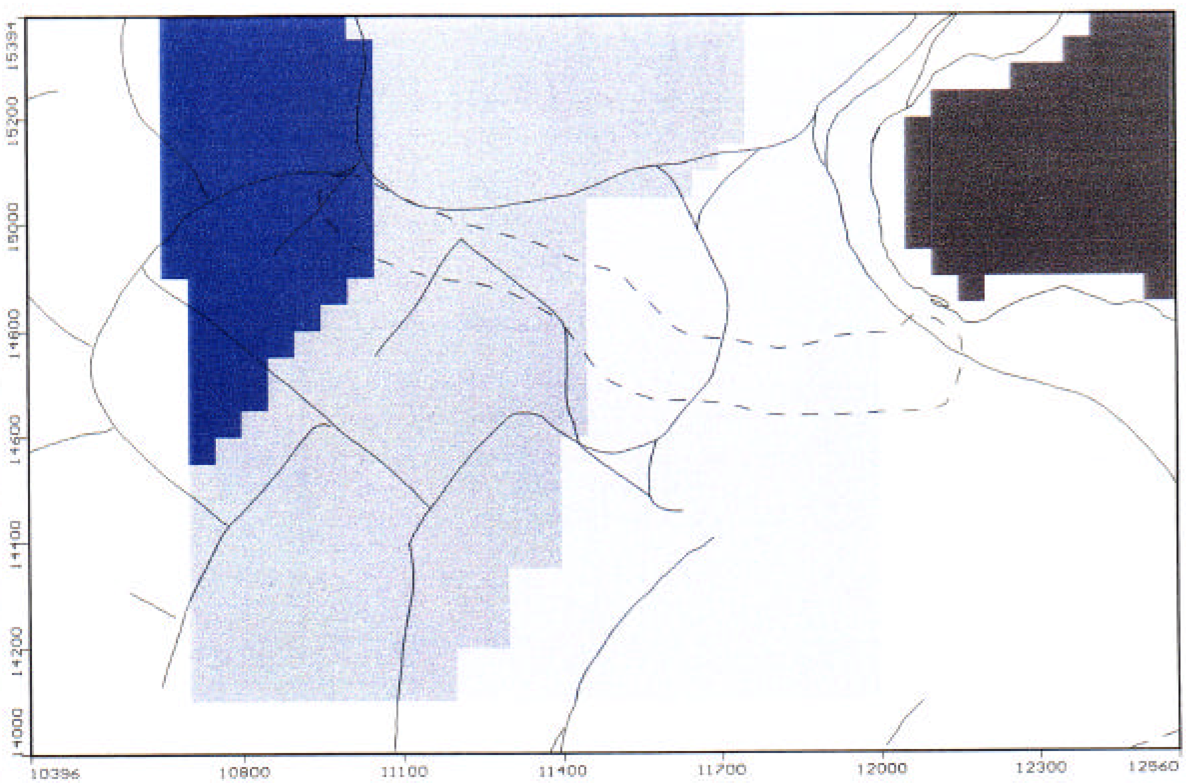



Figure 3: Hydraulic Conductivity, South of Tailings, Layer 3

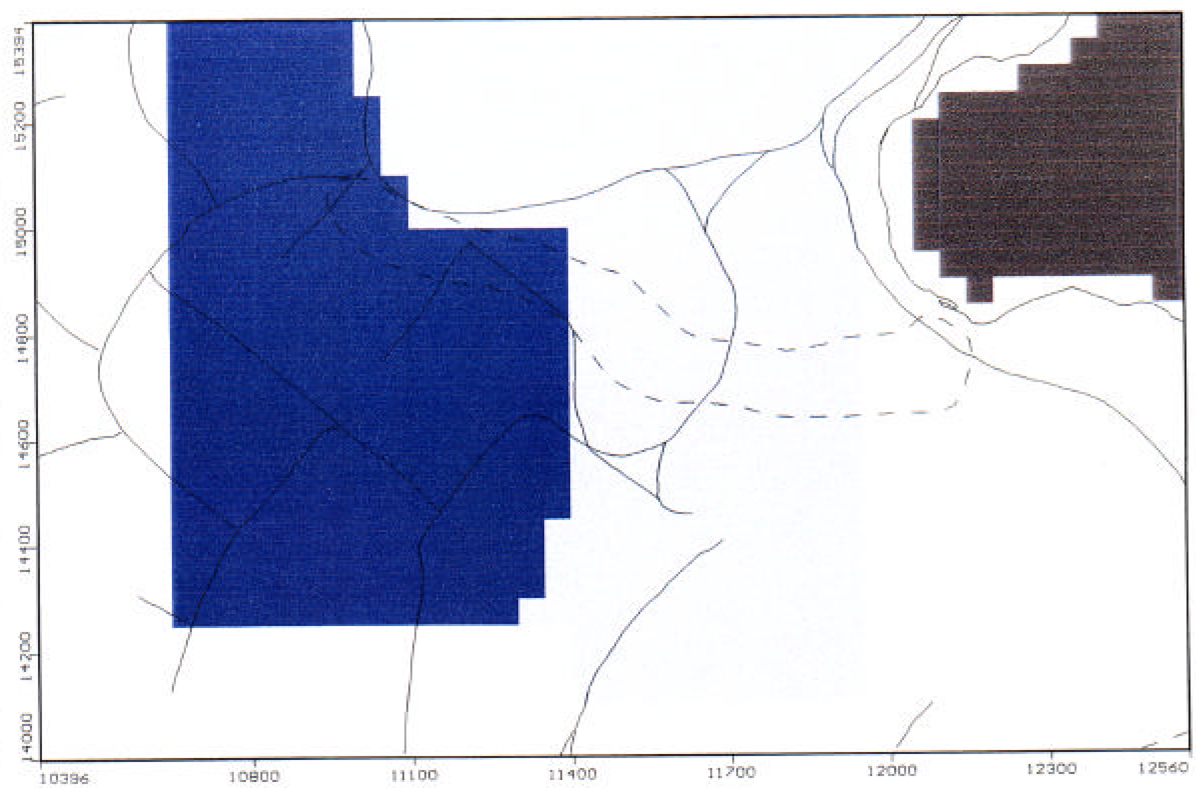



Figure 4: Hydraulic Conductivity, South of Tailings, Layer 4

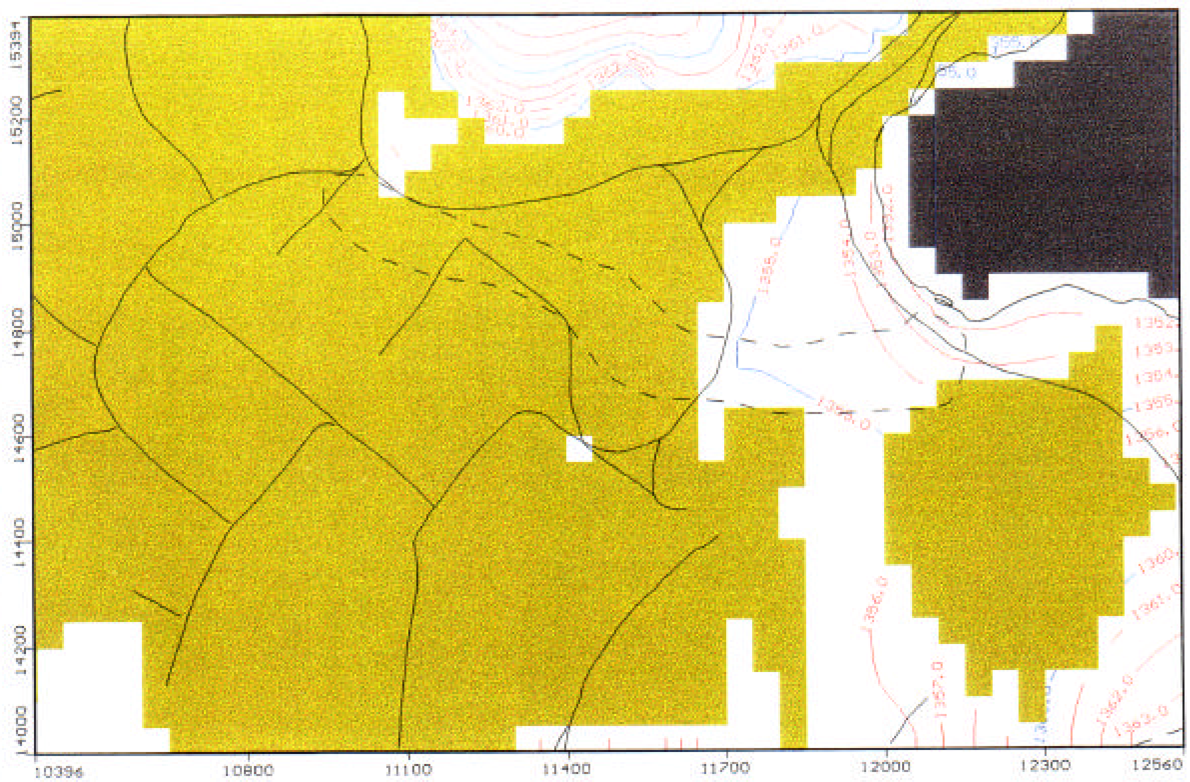



Figure 5: Equipotentials (fasl), South of Tailings, Layer 1

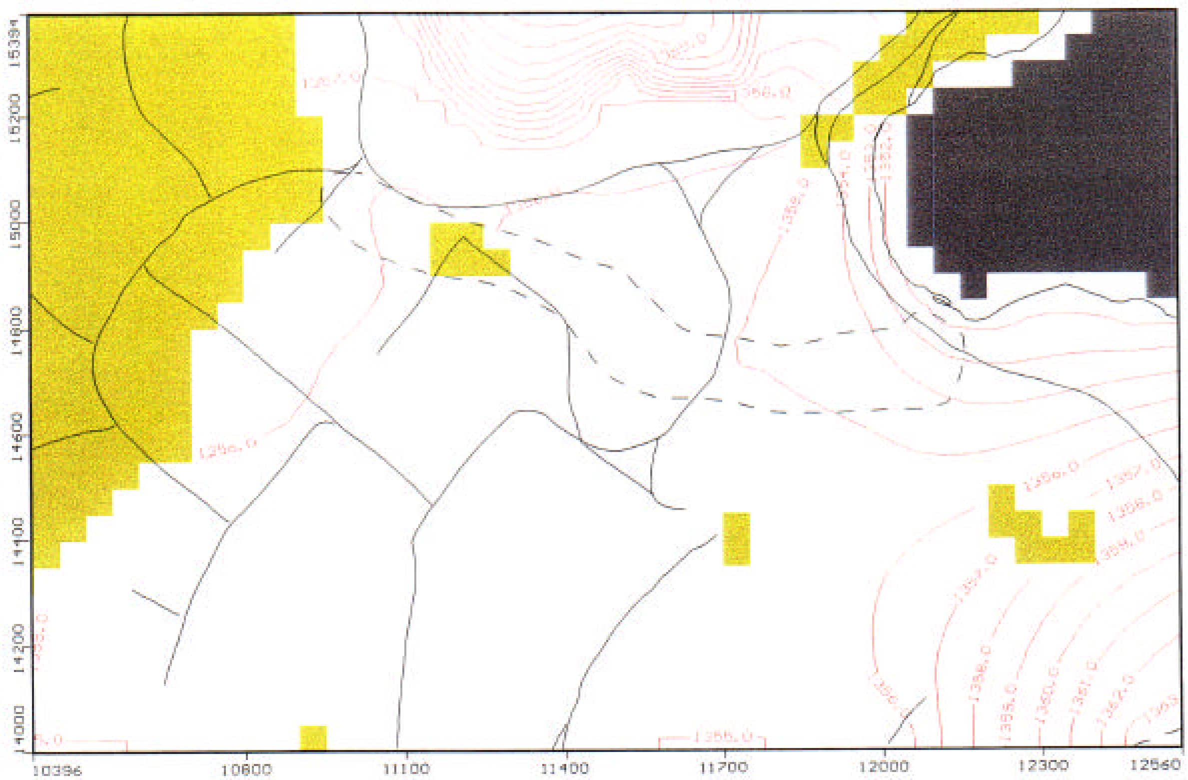



Figure 6: Equipotentials (fasl), South of Tailings, Layer 2

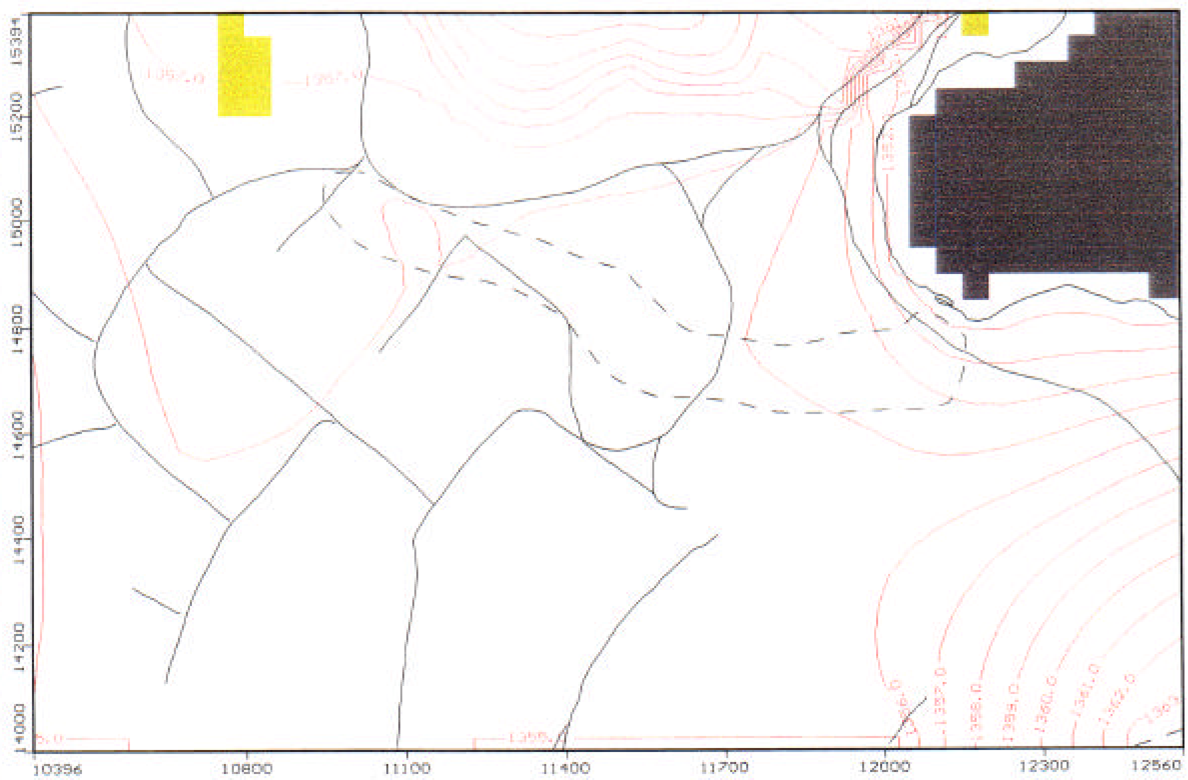



Figure 7: Equipotentials (fasl), South of Tailings, Layer 3

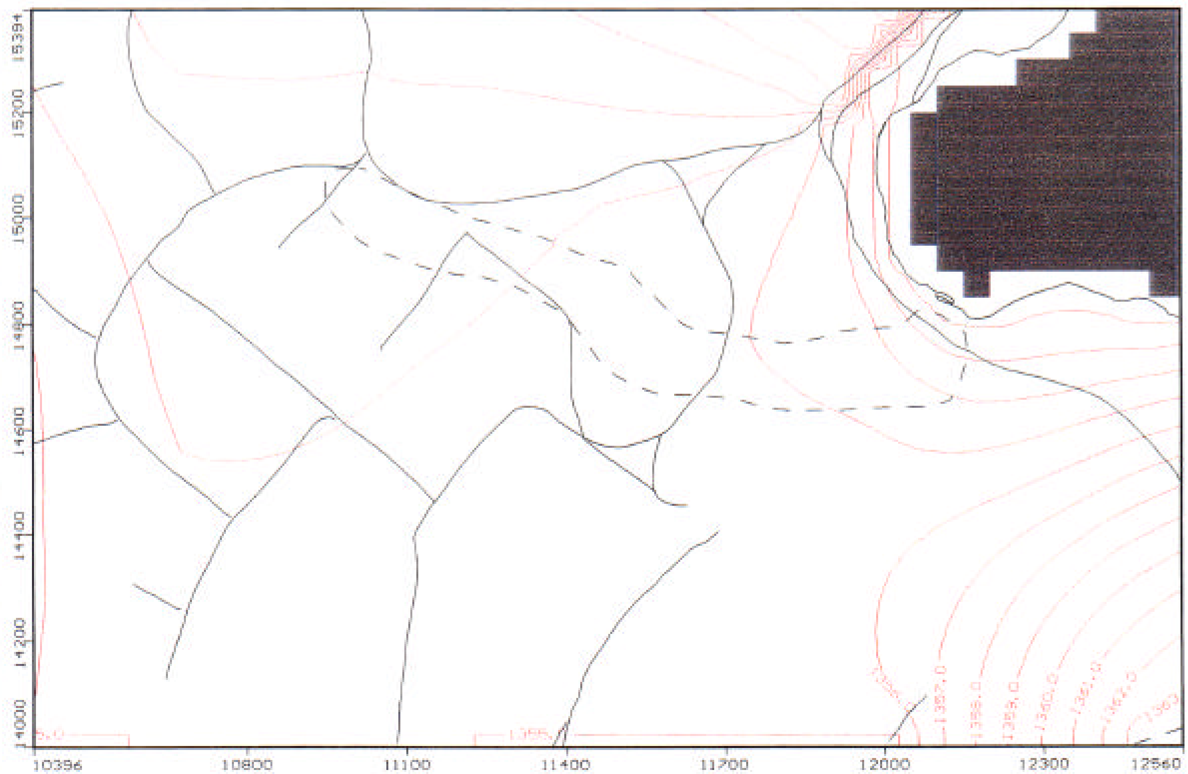



Figure 8: Equipotentials (fasl), South of Tailings, Layer 4

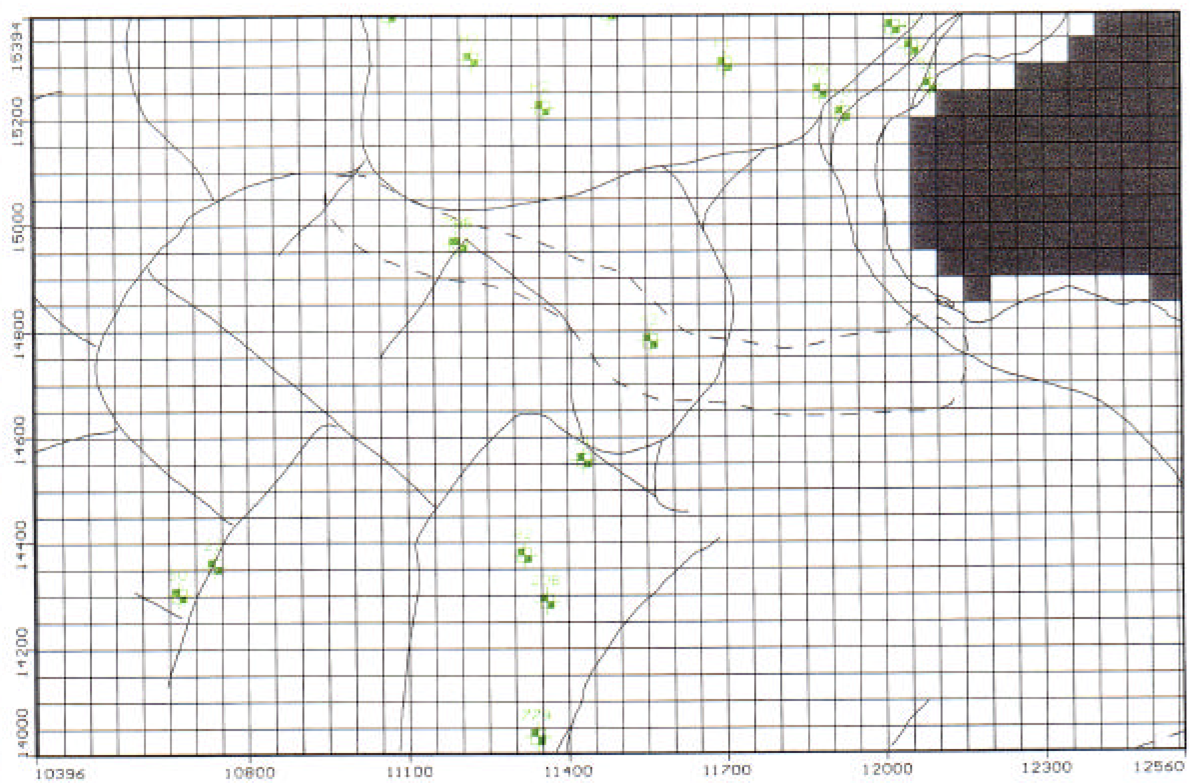
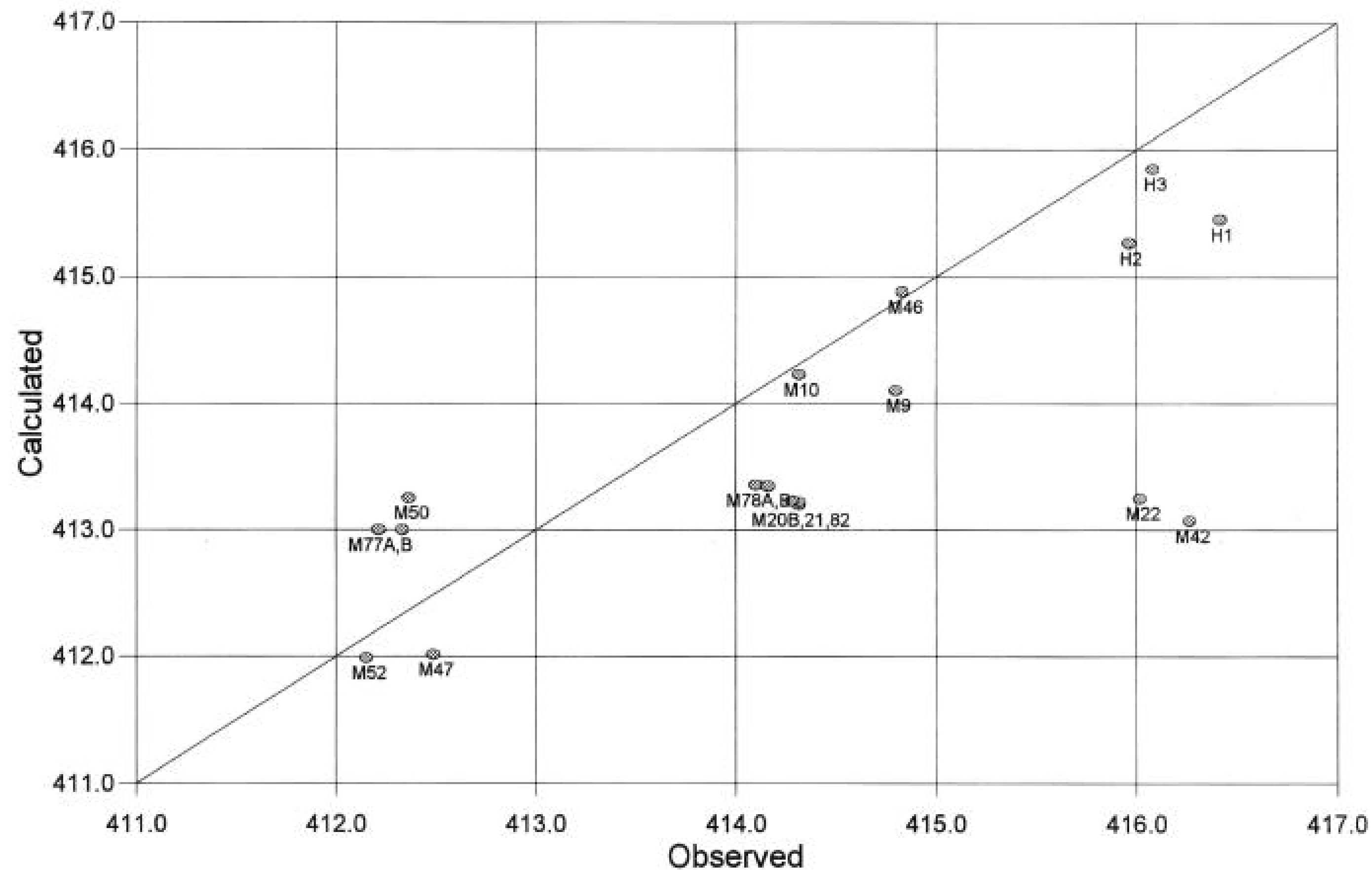



Figure 9: Monitoring Wells in Modelled Domain

Fig. 10: Observed vs Calculated Heads,
Piezometers Located South of Tailings



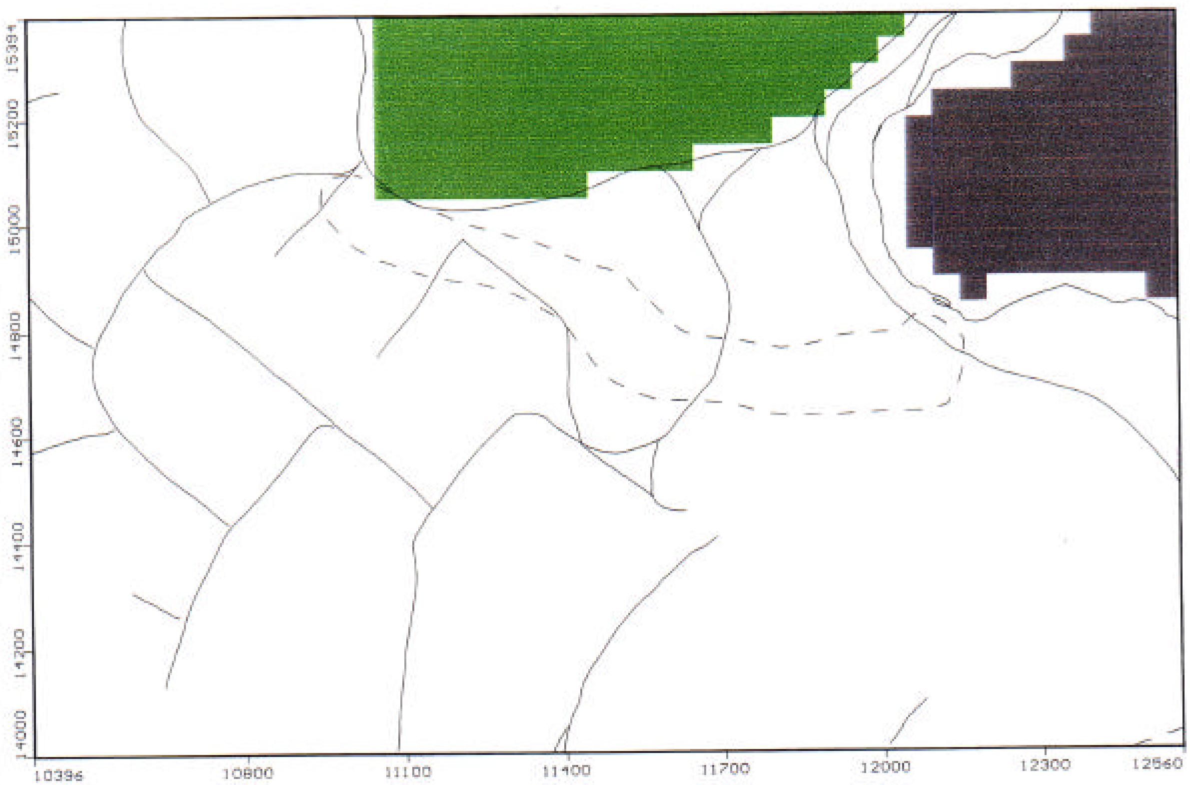



Figure 11: Constant Concentration (Zinc, 700 mg/L), Layer 1


Figure 12: Constant Concentration (Zinc, 700 mg/L), Layer 2


Figure 13: Zinc Concentration in Contaminant Plume from Tailings at 5 years, Layer 1 (interval 100 mg/L)

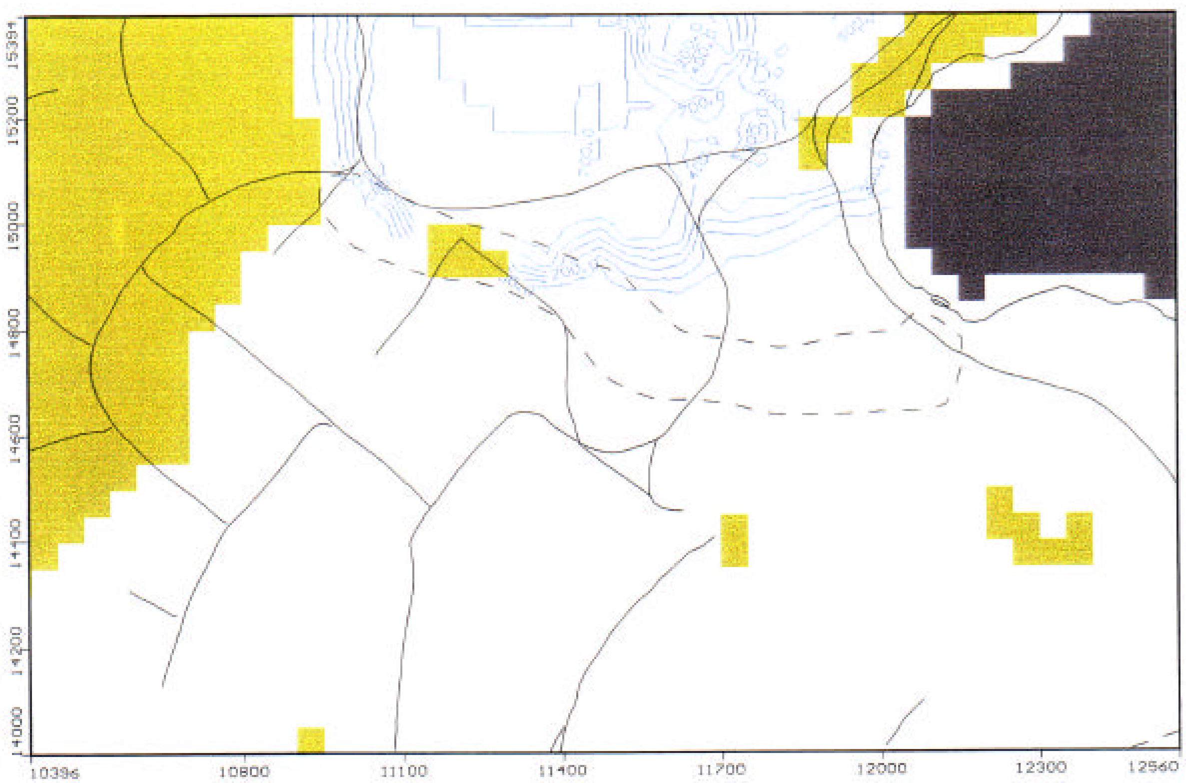



Figure 14: Zinc Concentration in Contaminant Plume from Tailings at 5 years, Layer 2 (interval 100 mg/L)

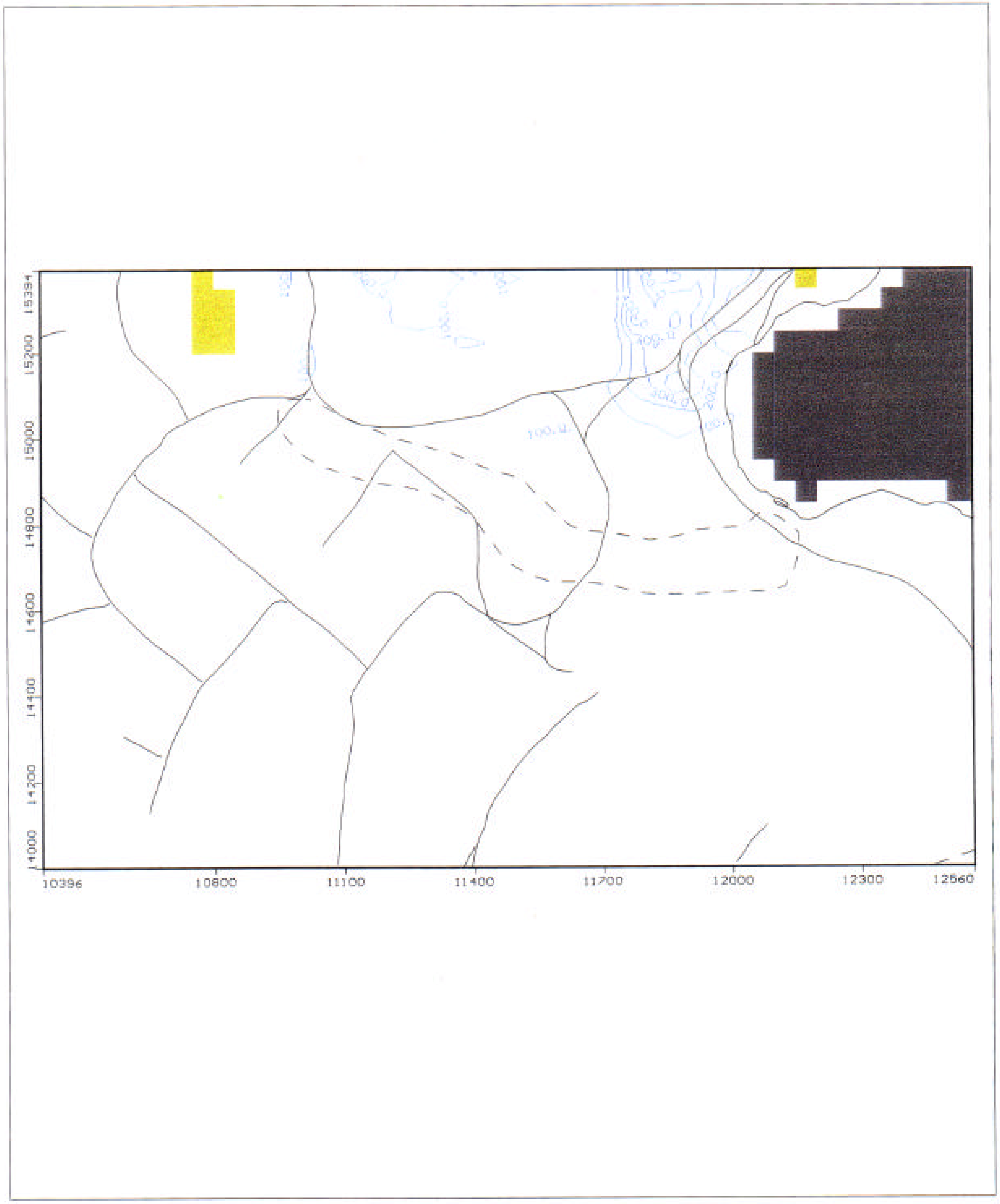



Figure 15: Zinc Concentration in Contaminant Plume from Tailings at 5 years, Layer 3 (interval 100 mg/L)

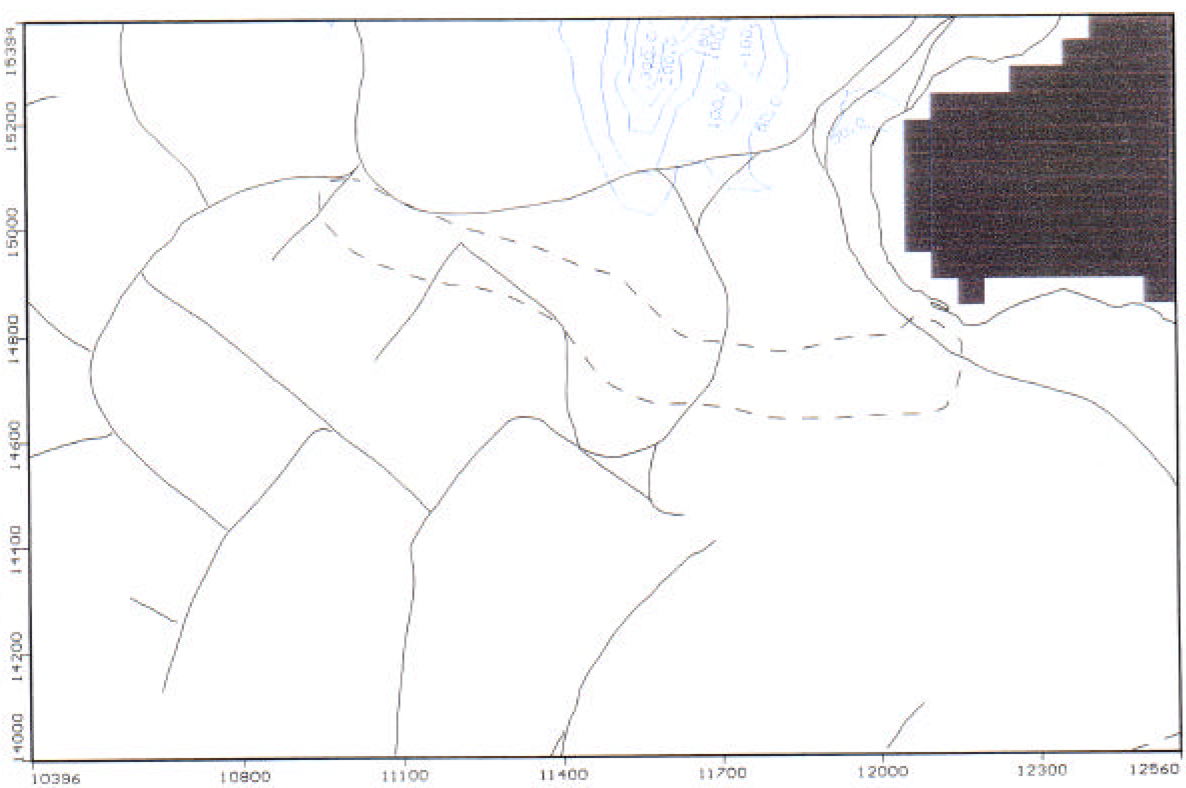



Figure 16: Zinc Concentration in Contaminant Plume from Tailings at 5 years, Layer 4 (interval 100 mg/L)

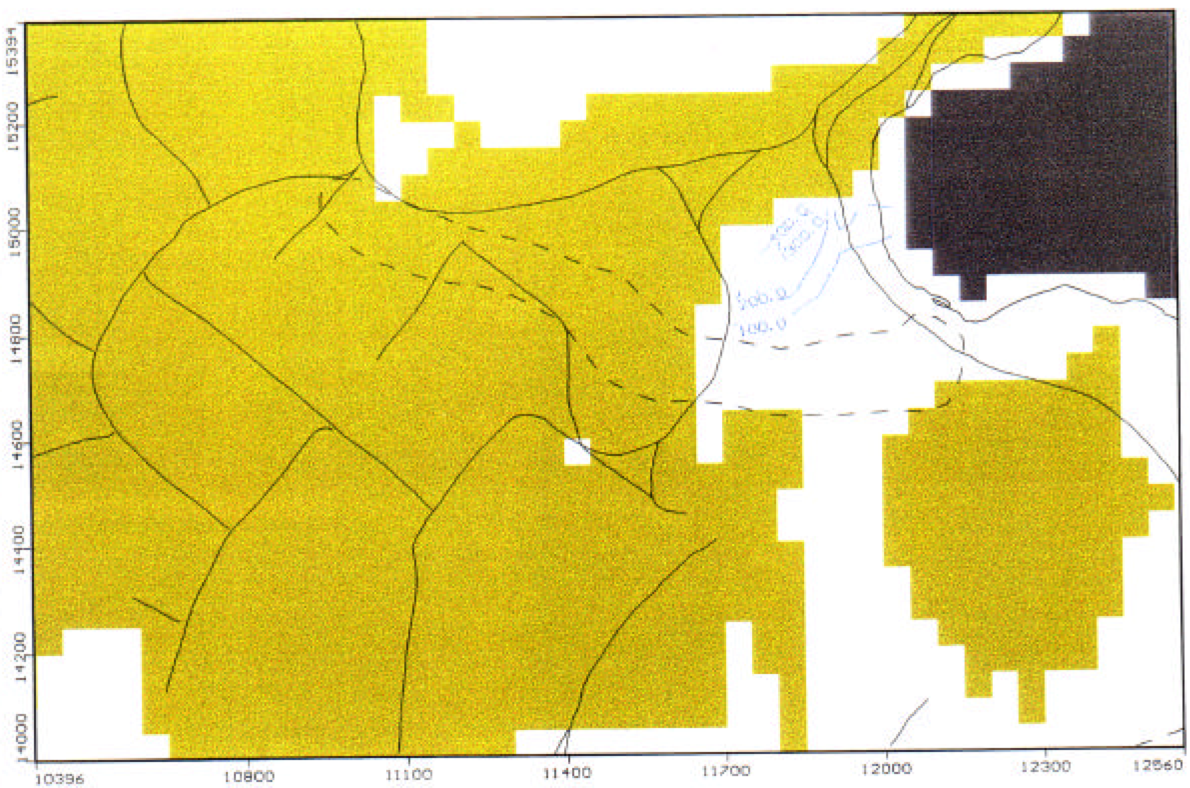



Figure 17: Zinc Concentration in Contaminant Plume from Tailings at 10 years, Layer 1 (interval 100 mg/L)

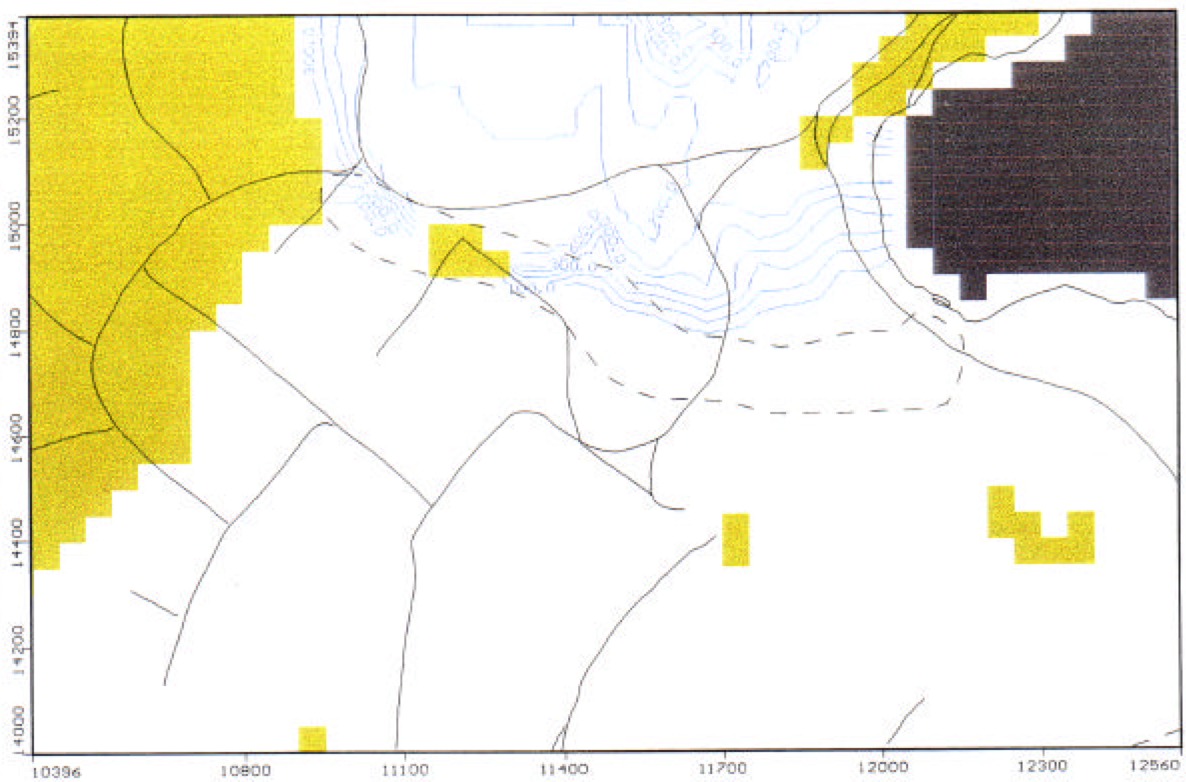



Figure 18: Zinc Concentration in Contaminant Plume from Tailings at 10 years, Layer 2 (interval 100 mg/L)

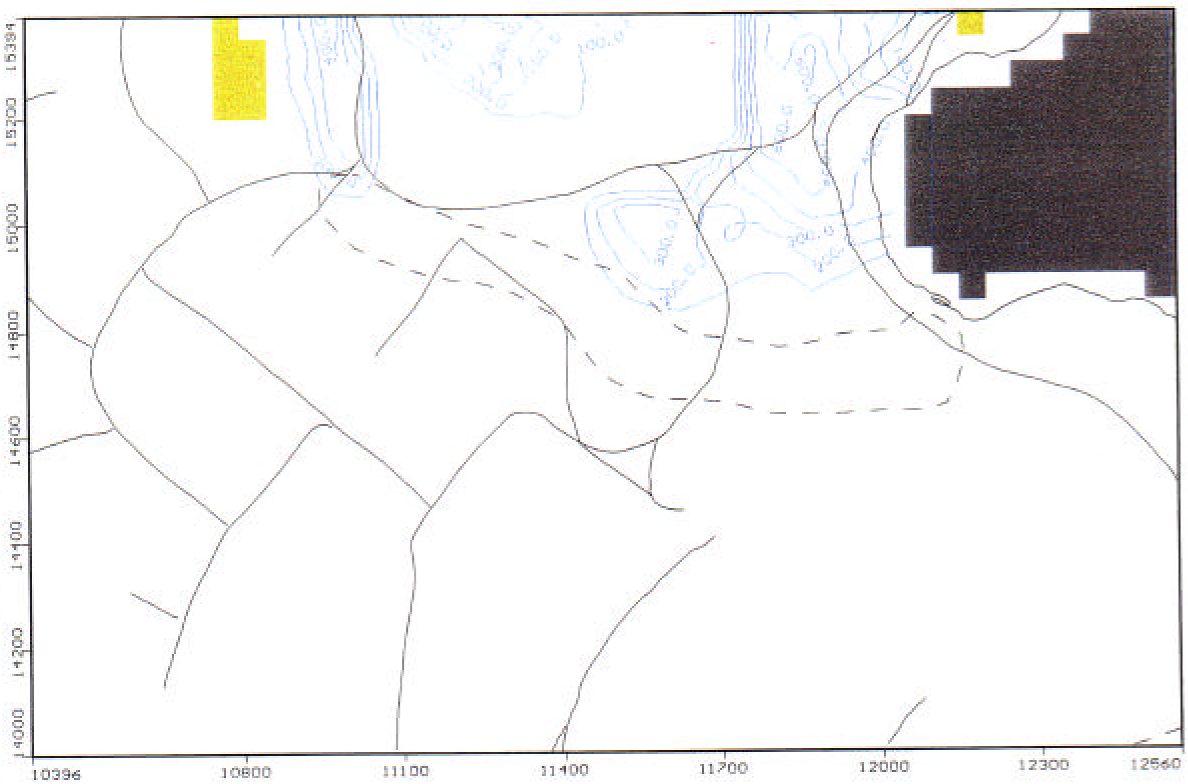



Figure 19: Zinc Concentration in Contaminant Plume from Tailings at 10 years, Layer 3 (interval 100 mg/L)

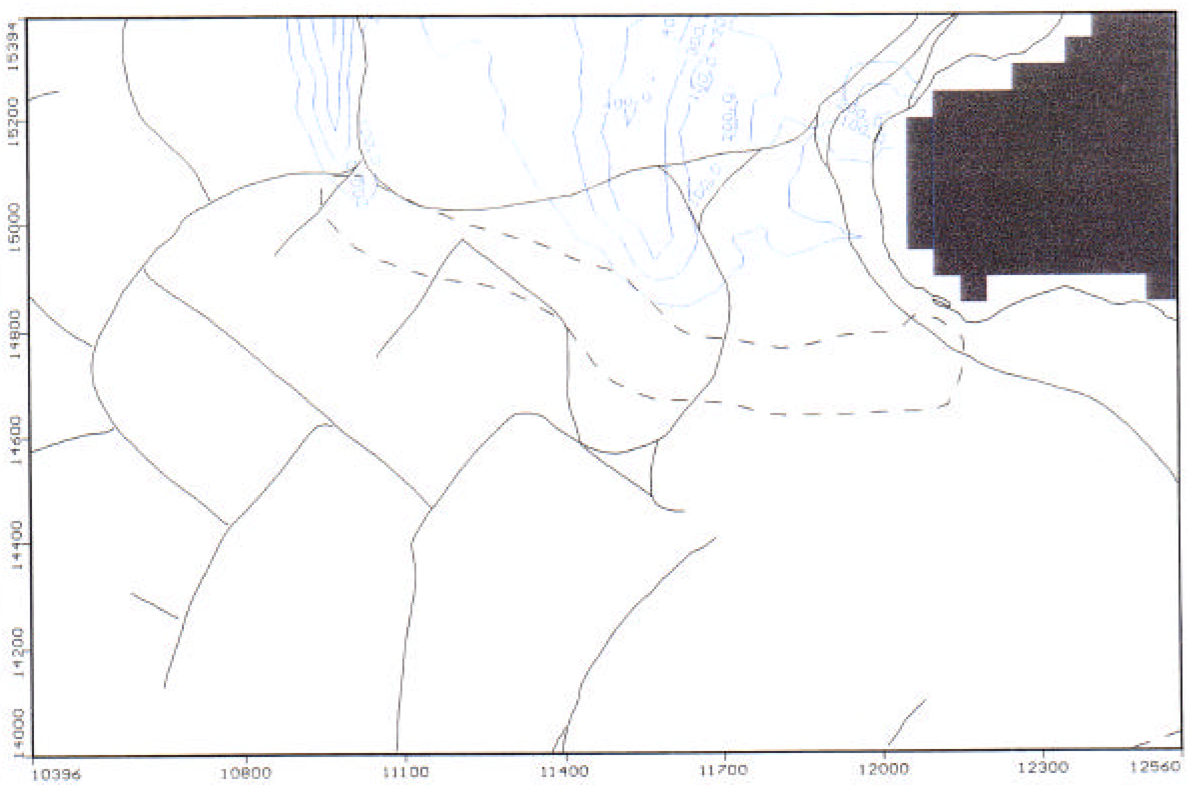



Figure 20: Zinc Concentration in Contaminant Plume from Tailings at 10 years, Layer 4 (interval 100 mg/L)


Figure 21: Zinc Concentration in Contaminant Plume from Tailings at 15 years, Layer 1 (interval 100 mg/L)

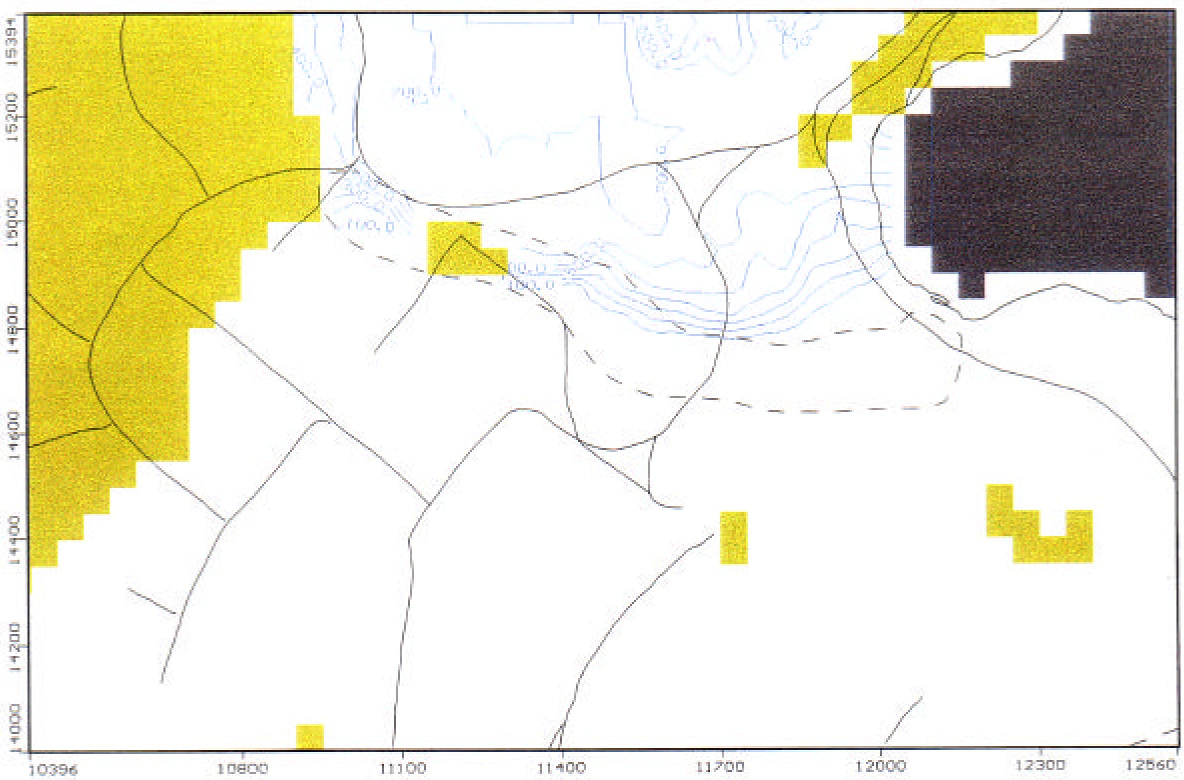



Figure 22: Zinc Concentration in Contaminant Plume from Tailings at 15 years, Layer 2 (interval 100 mg/L)

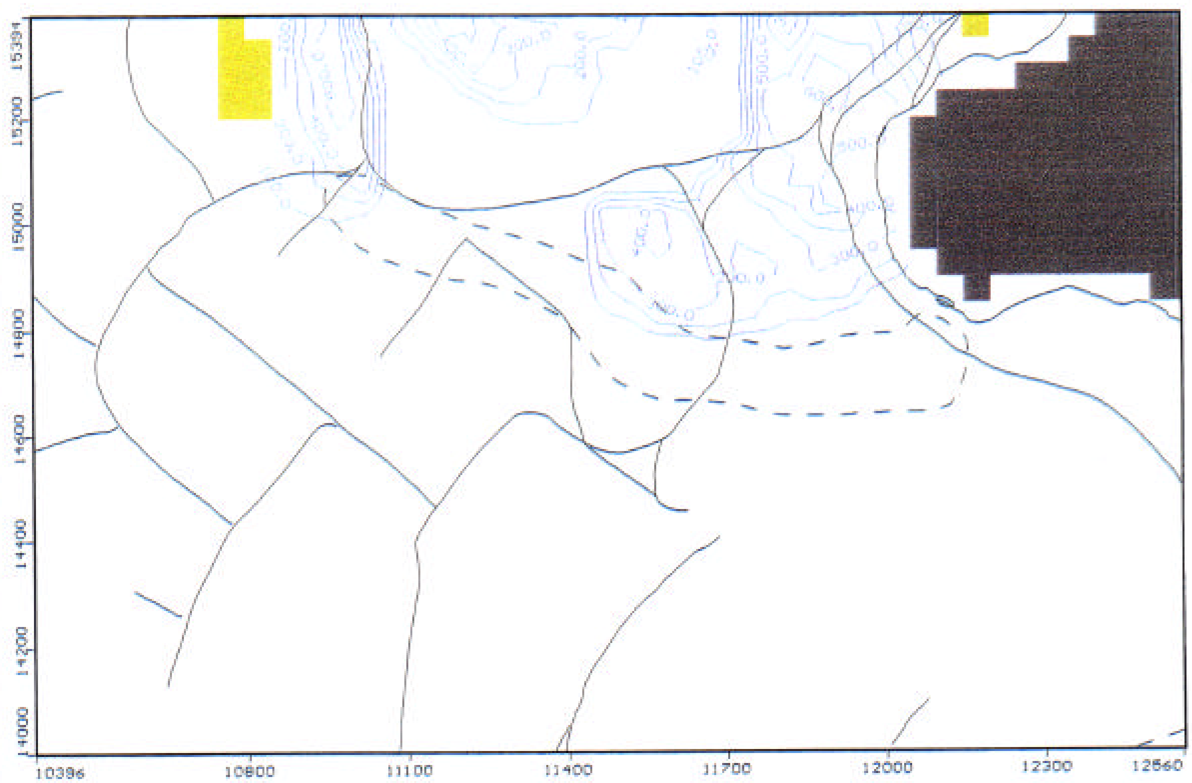



Figure 23: Zinc Concentration in Contaminant Plume from Tailings at 15 years, Layer 3 (interval 100 mg/L)

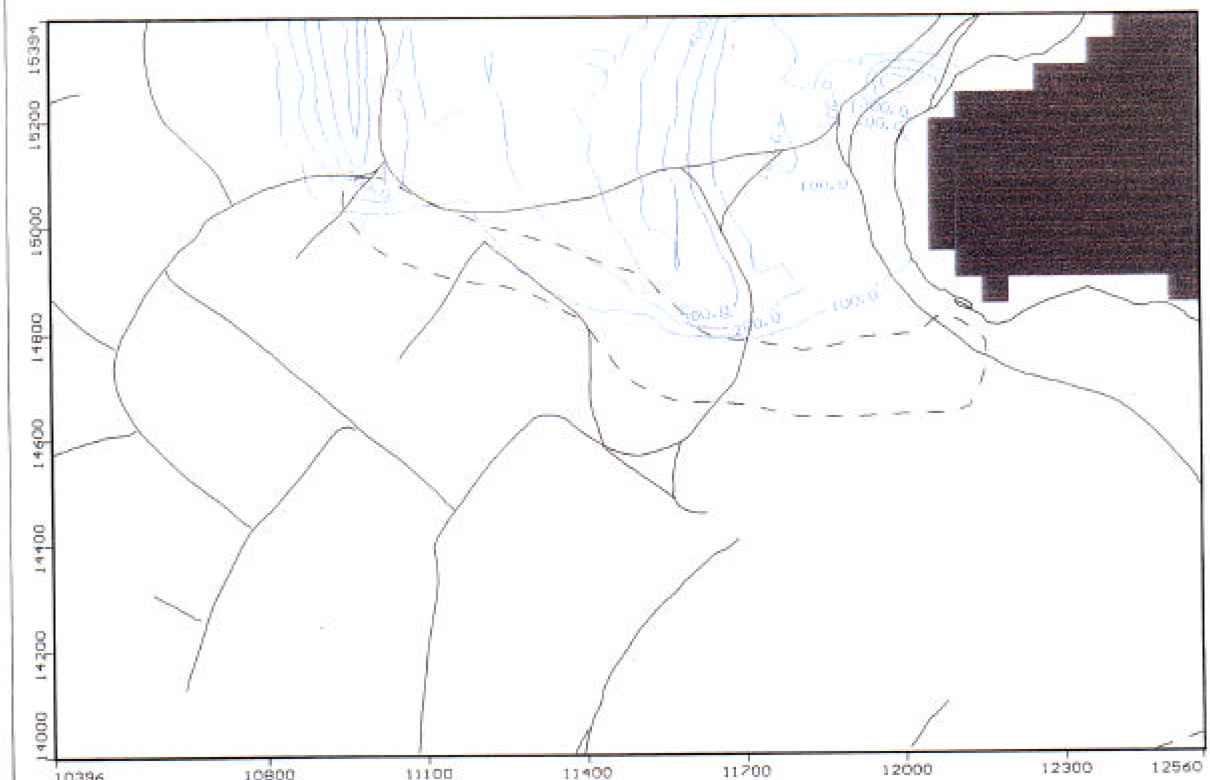



Figure 24: Zinc Concentration in Contaminant Plume from Tailings at 15 years, Layer 4 (interval 100 mg/L)

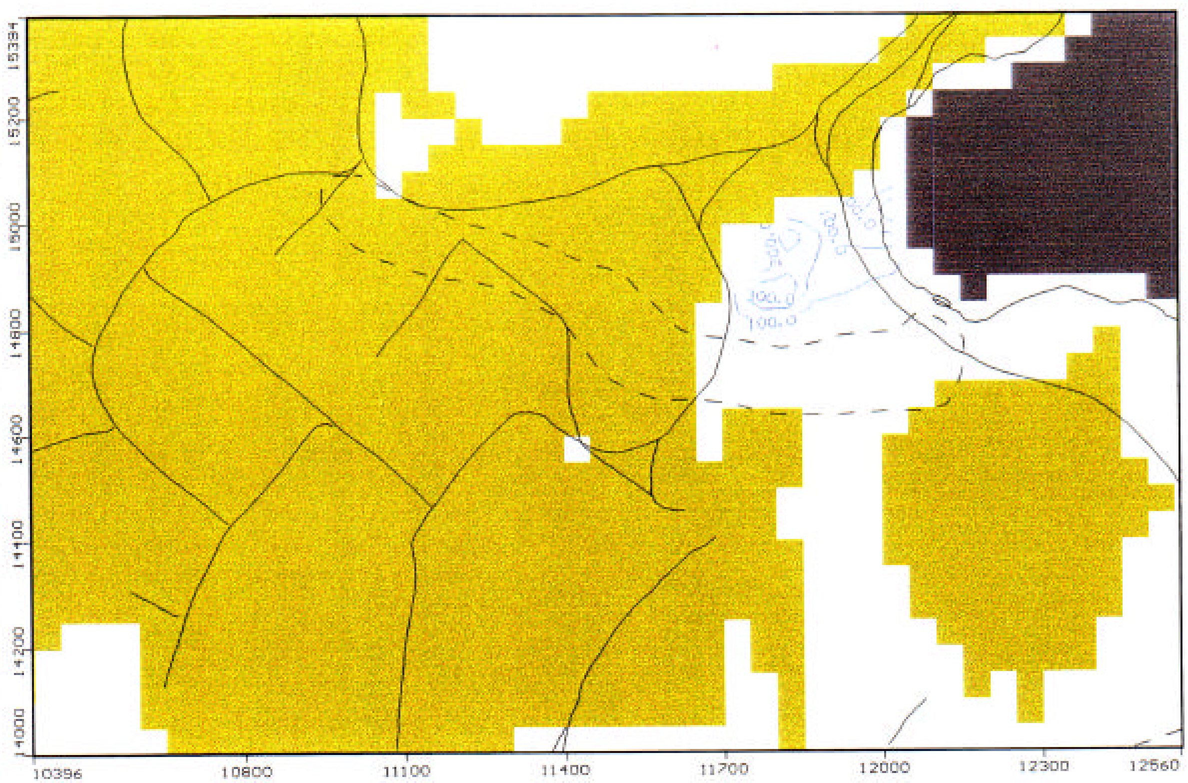



Figure 25: Zinc Concentration in Contaminant Plume from Tailings at 20 years, Layer 1 (interval 100 mg/L)

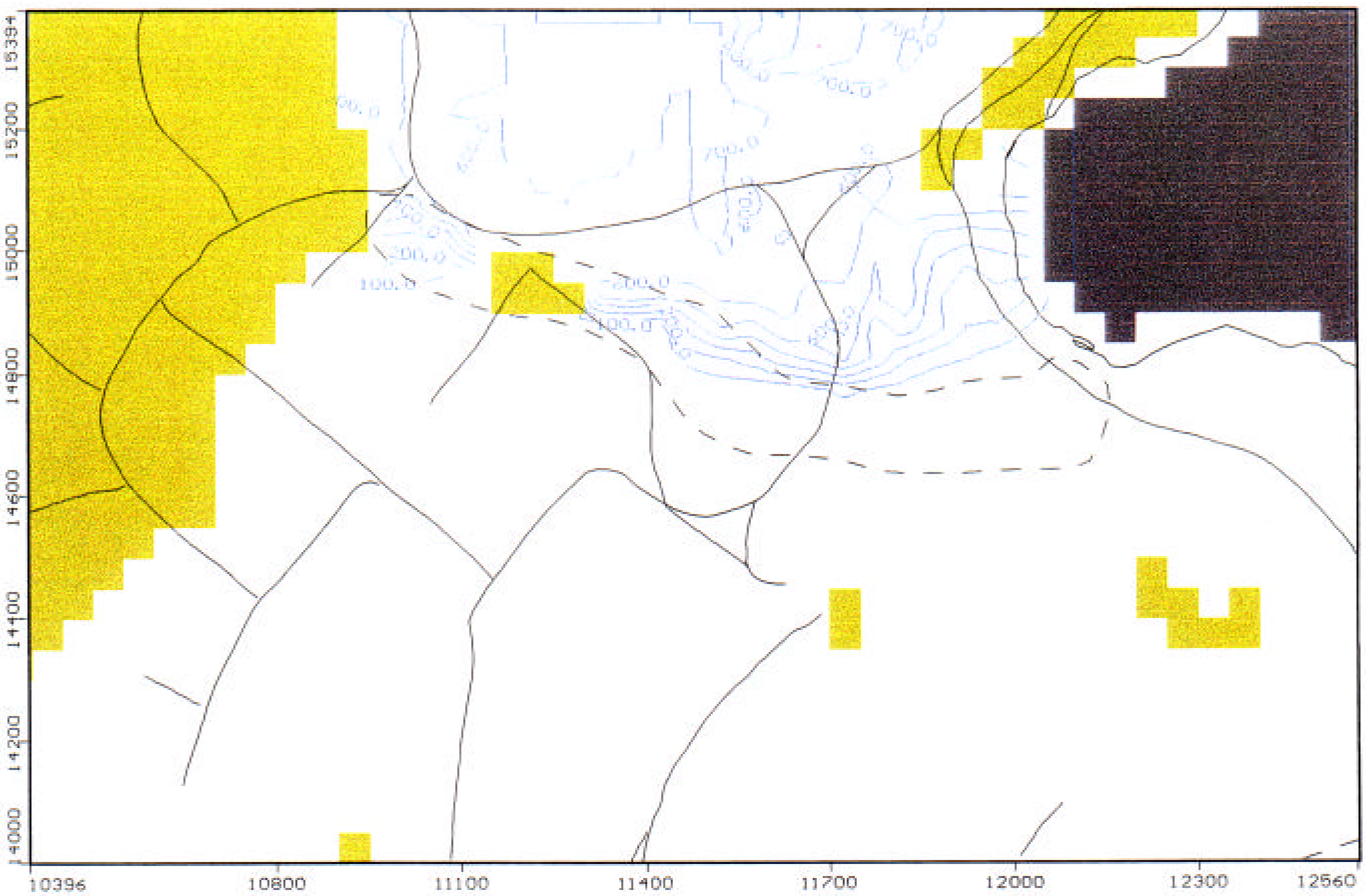



Figure 26: Zinc Concentration in Contaminant Plume from Tailings at 20 years, Layer 2 (interval 100 mg/L)

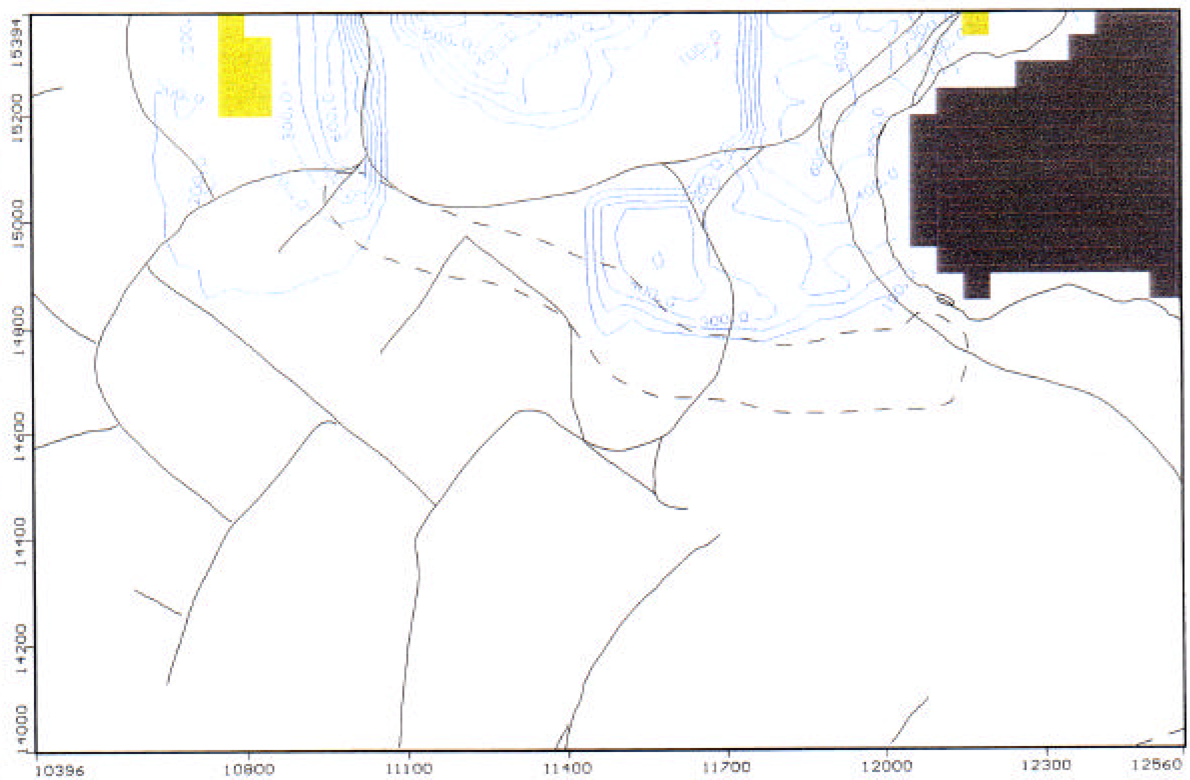



Figure 27: Zinc Concentration in Contaminant Plume from Tailings at 20 years, Layer 3 (interval 100 mg/L)

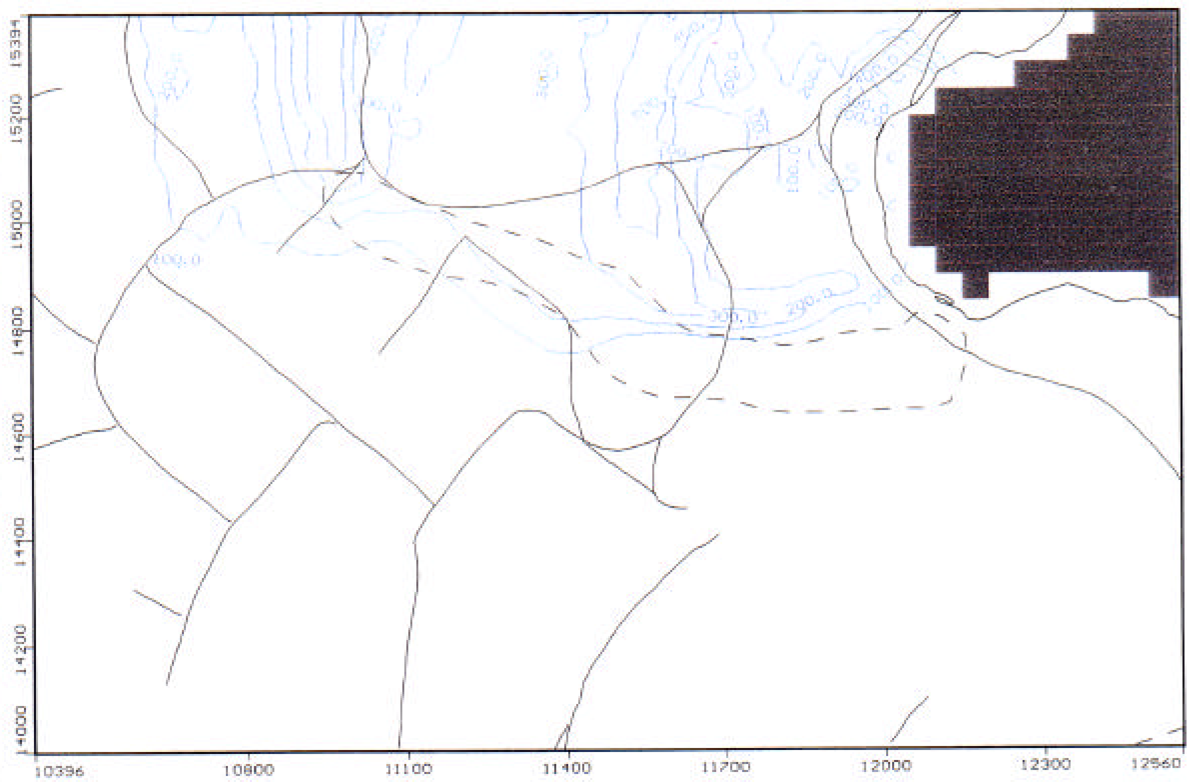



Figure 28: Zinc Concentration in Contaminant Plume from Tailings at 20 years, Layer 4 (interval 100 mg/L)

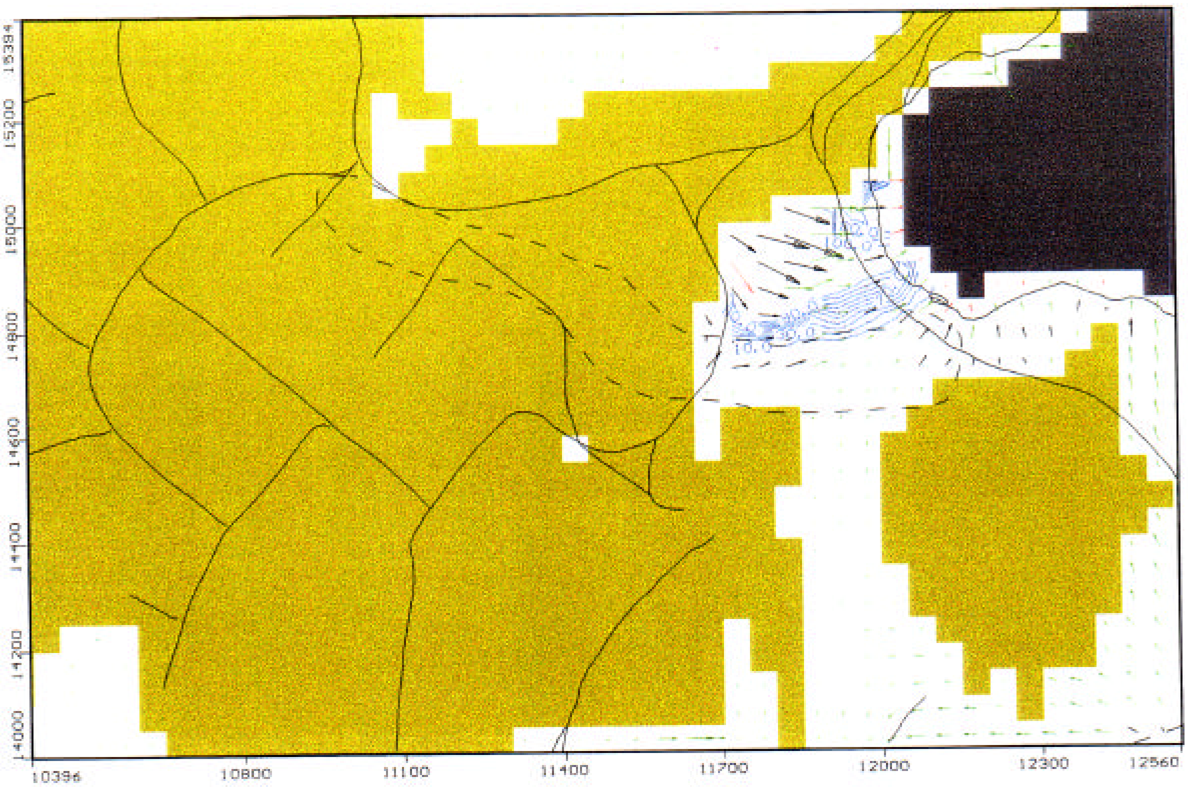



Figure 29: Zinc Concentration in Contaminant Plume from Tailings and Velocity Projection at 20 years, Layer 1 (interval 10 mg/L)

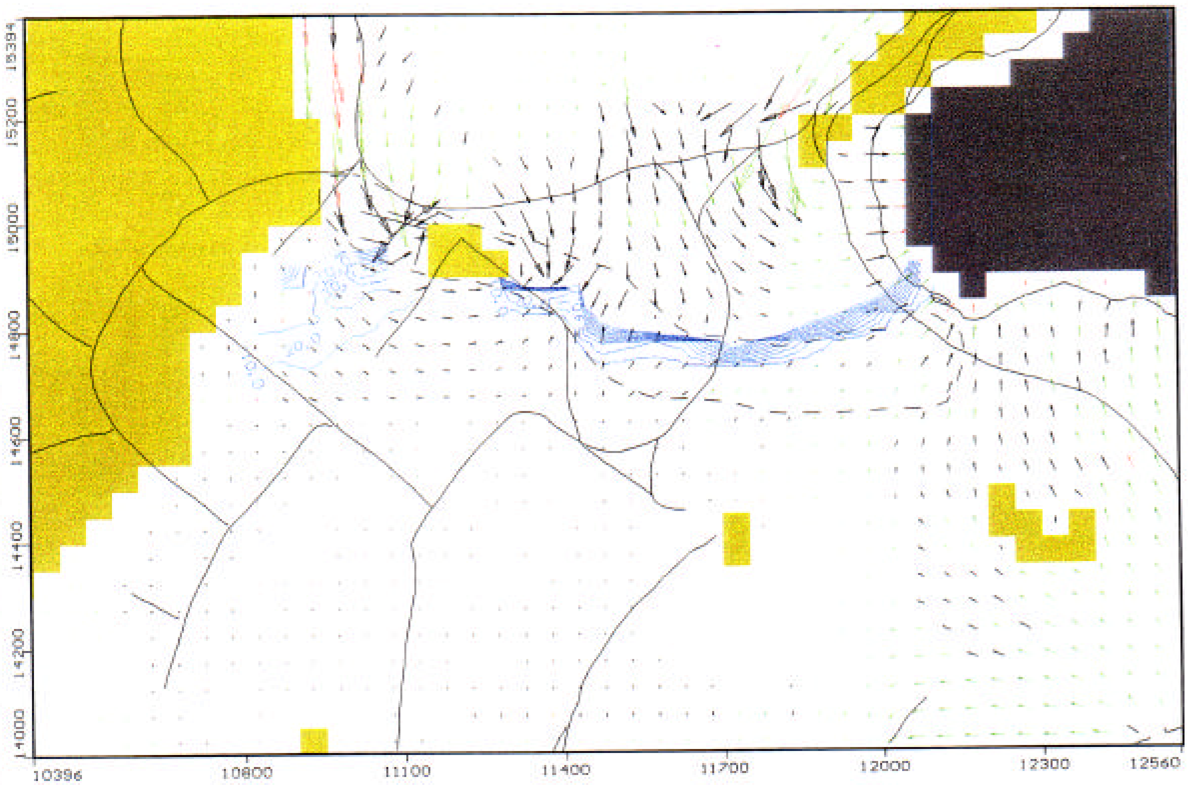



Figure 30: Zinc Concentration in Contaminant Plume from Tailings and Velocity Projection at 20 years, Layer 2 (interval 10 mg/L)

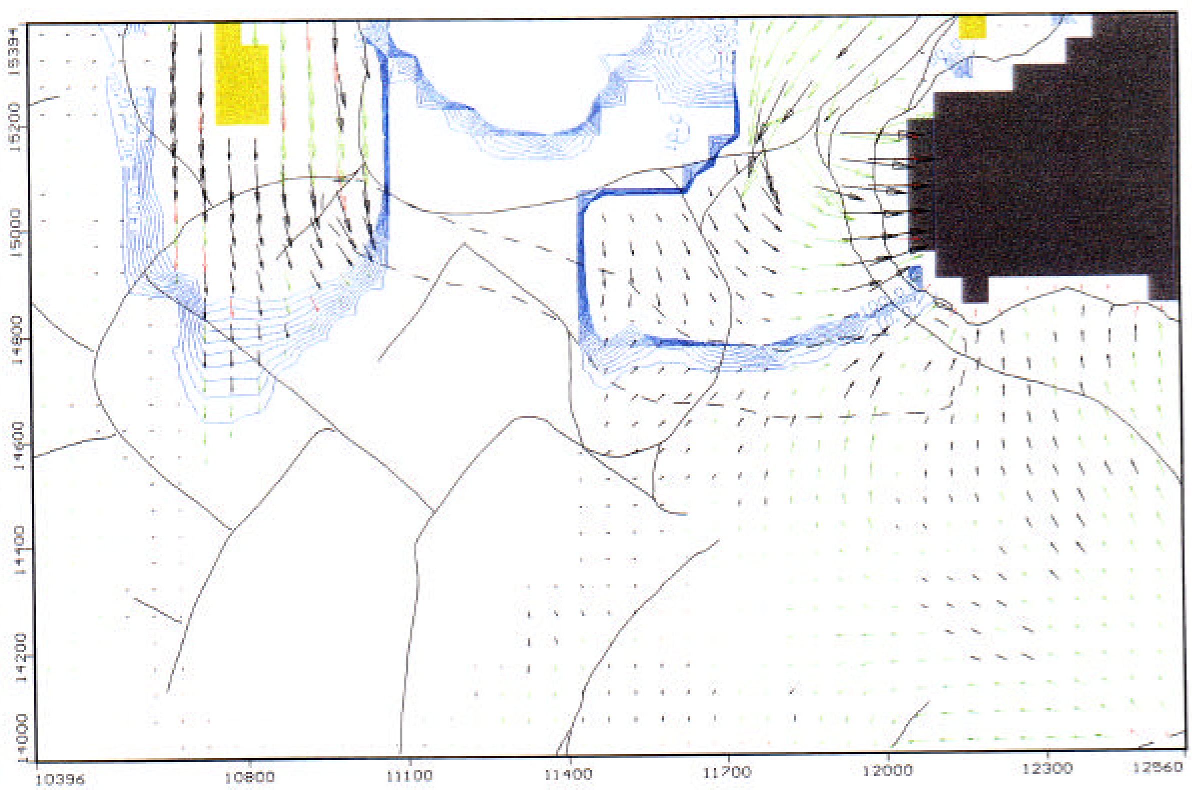



Figure 31: Zinc Concentration in Contaminant Plume from Tailings and Velocity Projection at 20 years, Layer 3 (interval 10 mg/L)

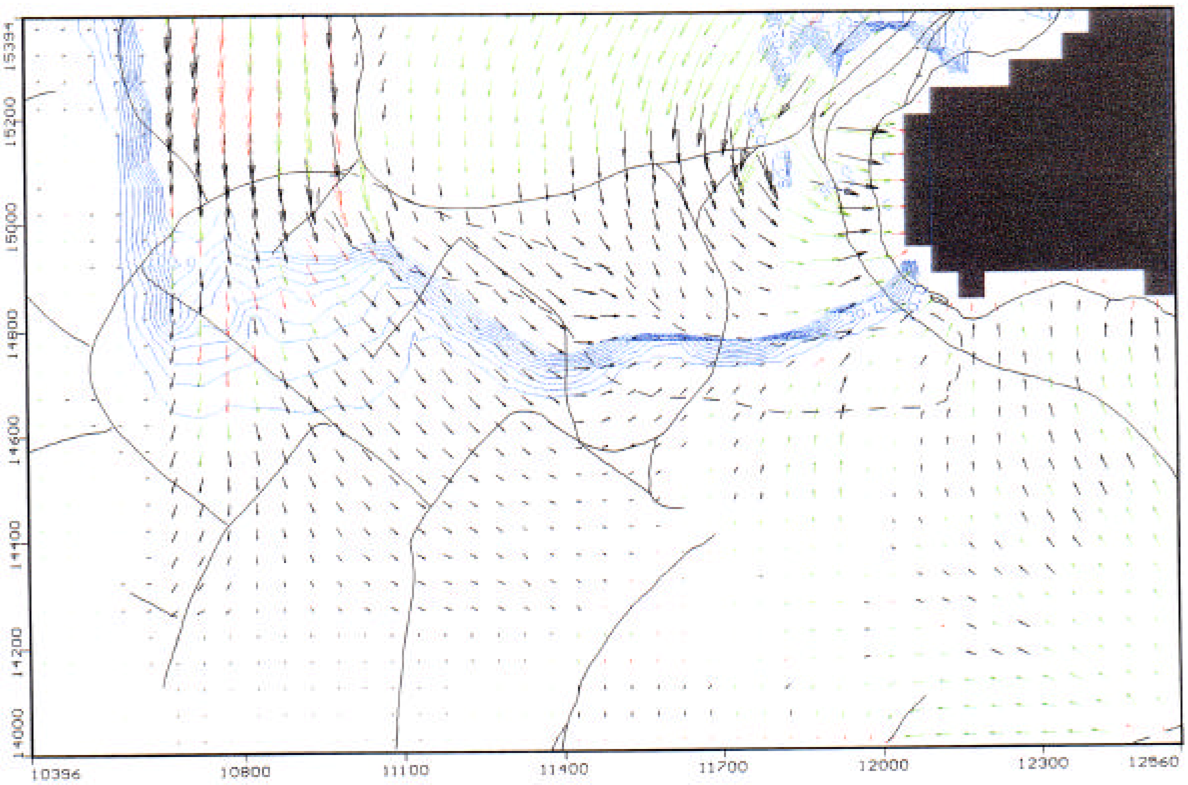



Figure 32: Zinc Concentration in Contaminant Plume from Tailings and Velocity Projection at 20 years, Layer 4 (interval 10 mg/L)

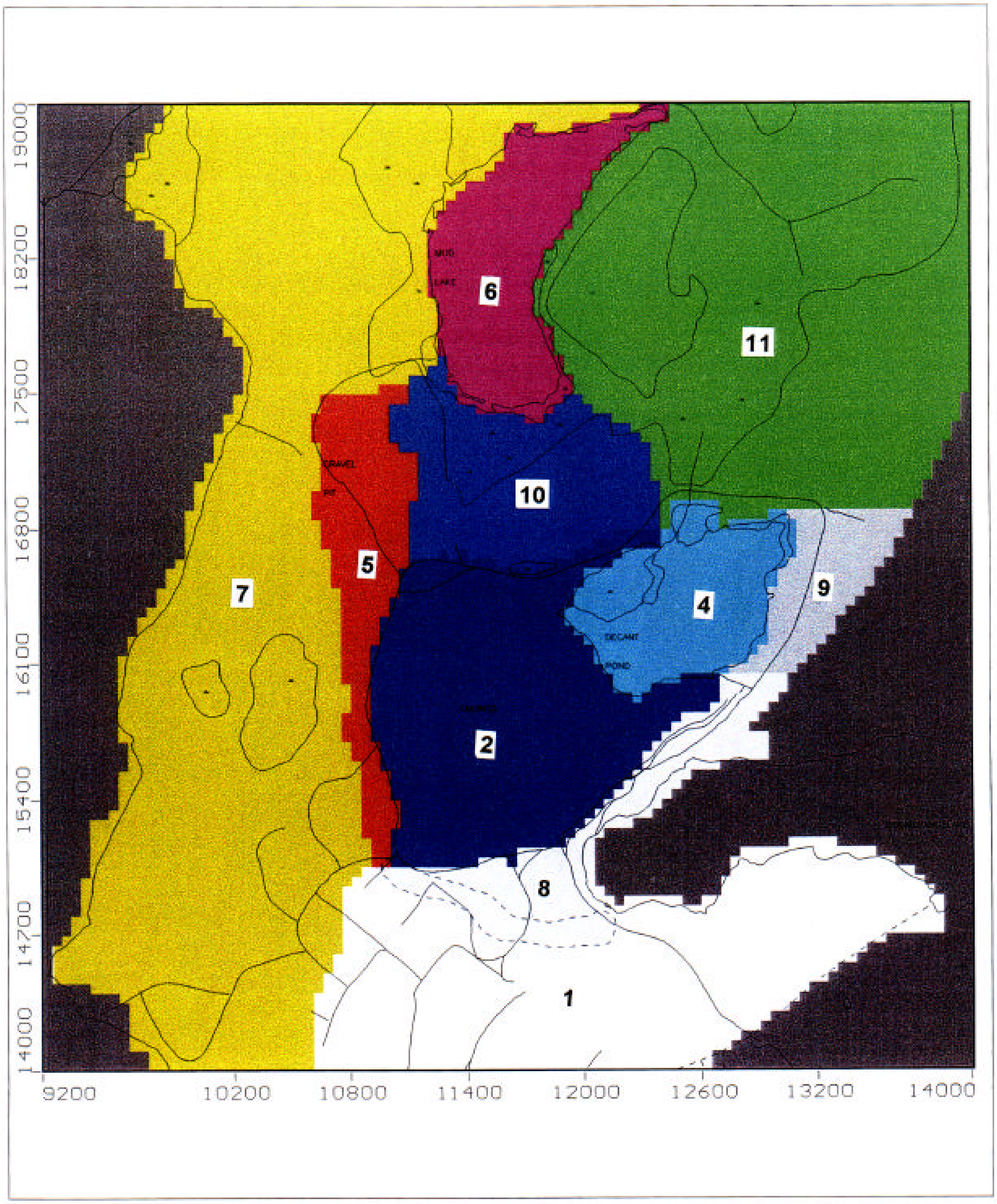



Figure 33: Flow Budget Zones, Layer 1

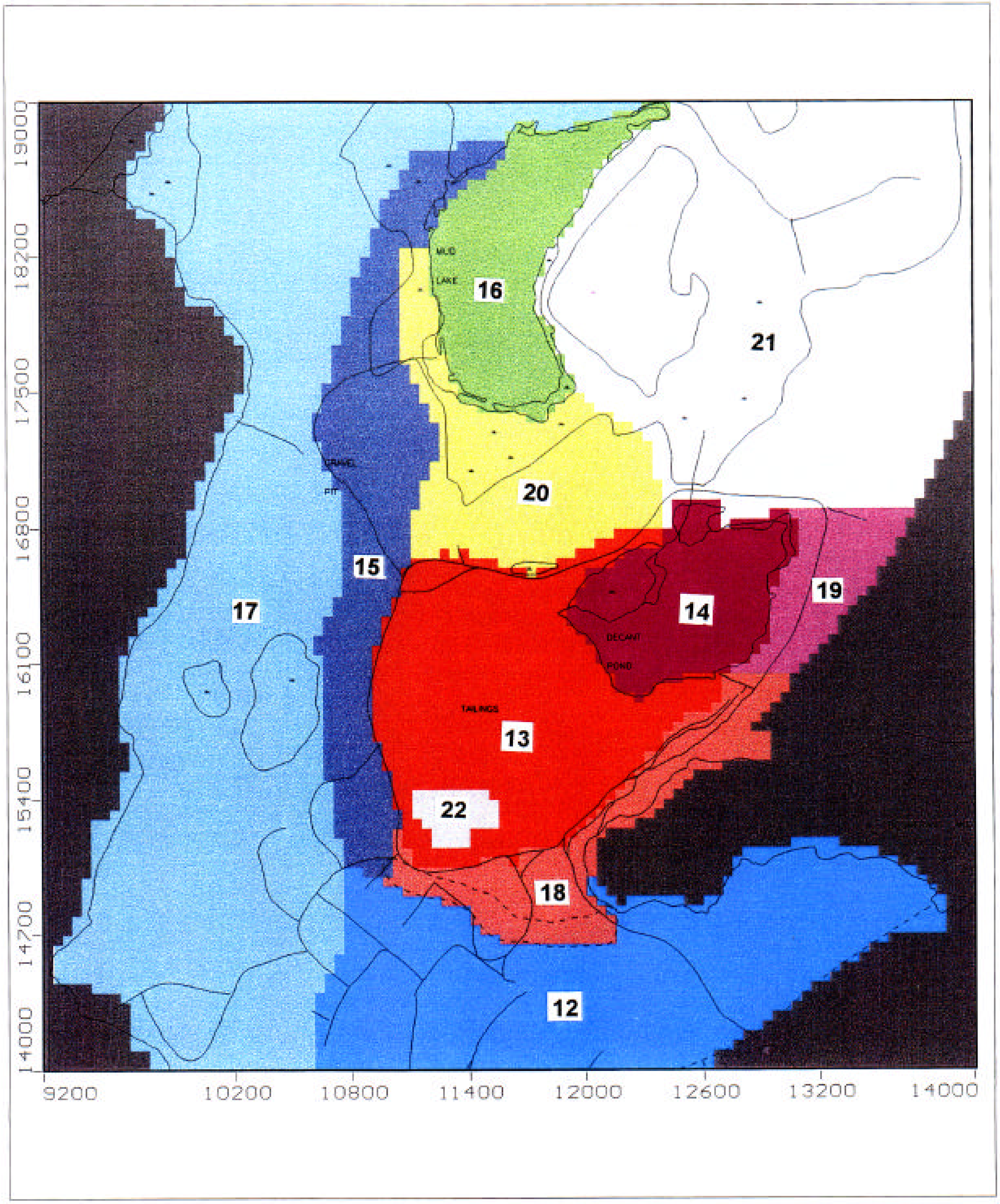



Figure 34: Flow Budget Zones, Layer 2

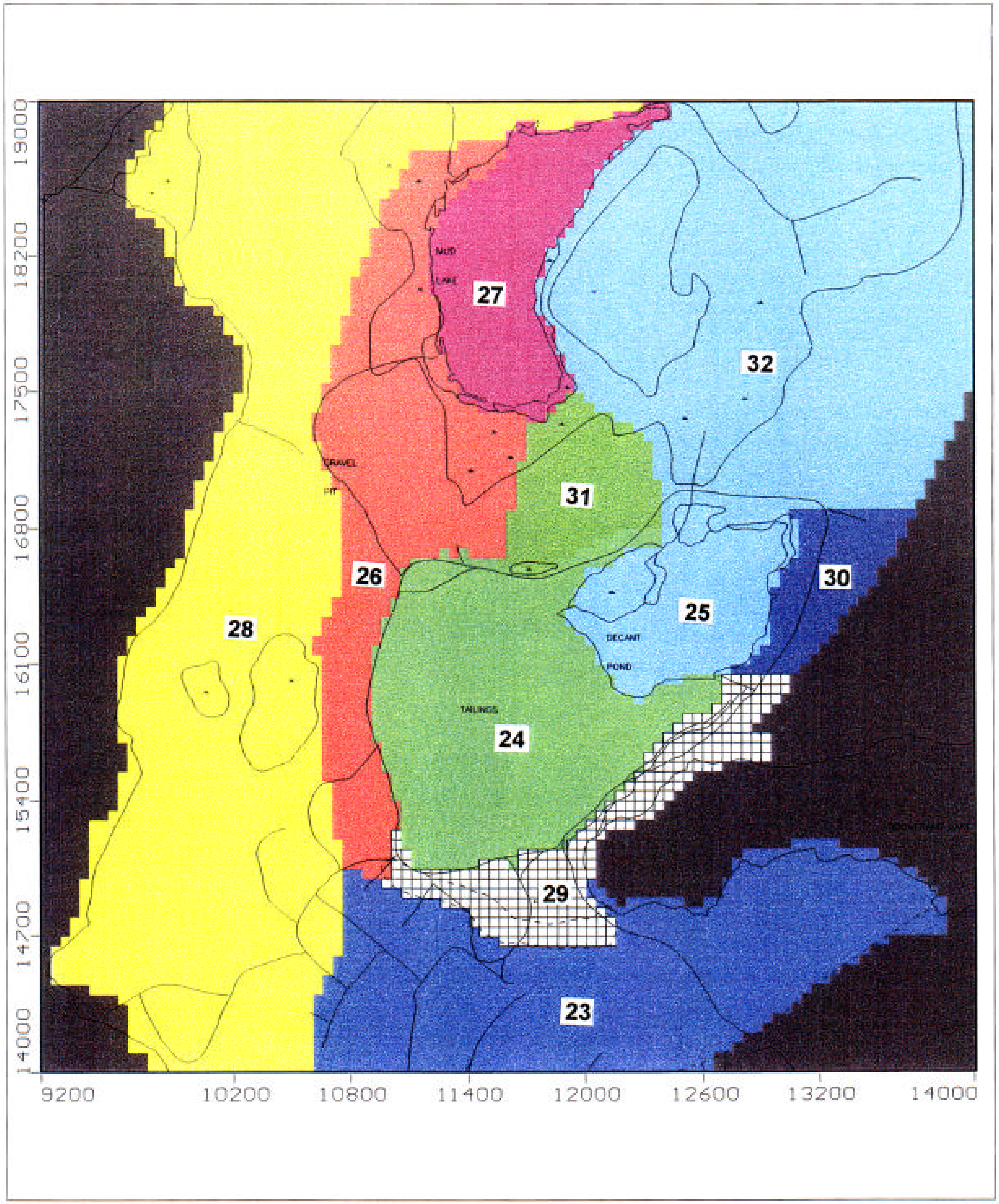



Figure 35: Flow Budget Zones, Layer 3

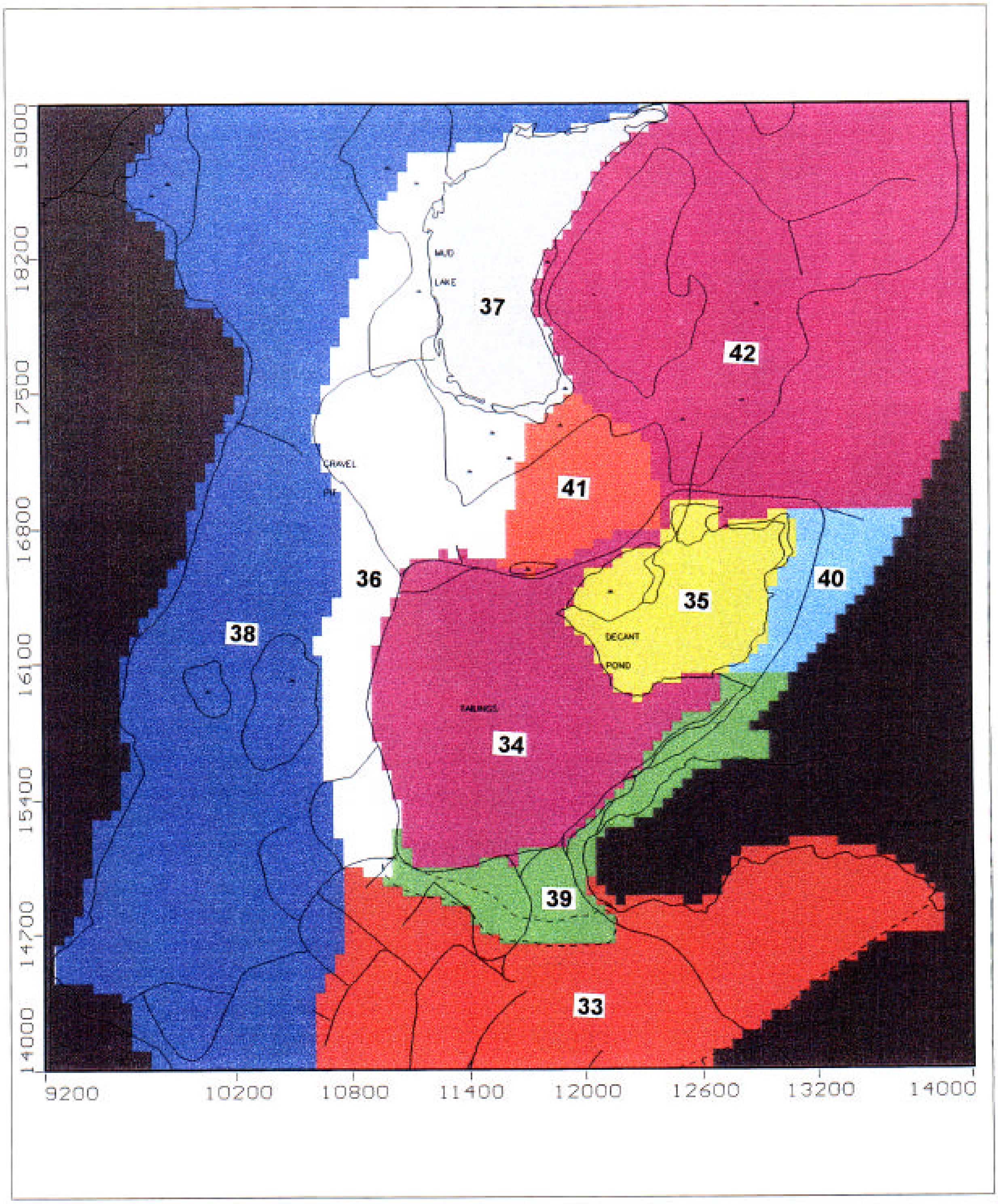



Figure 36: Flow Budget Zones, Layer 4

Figure 37: Elevation of water level in March in selected piezometers over period 1987-2000

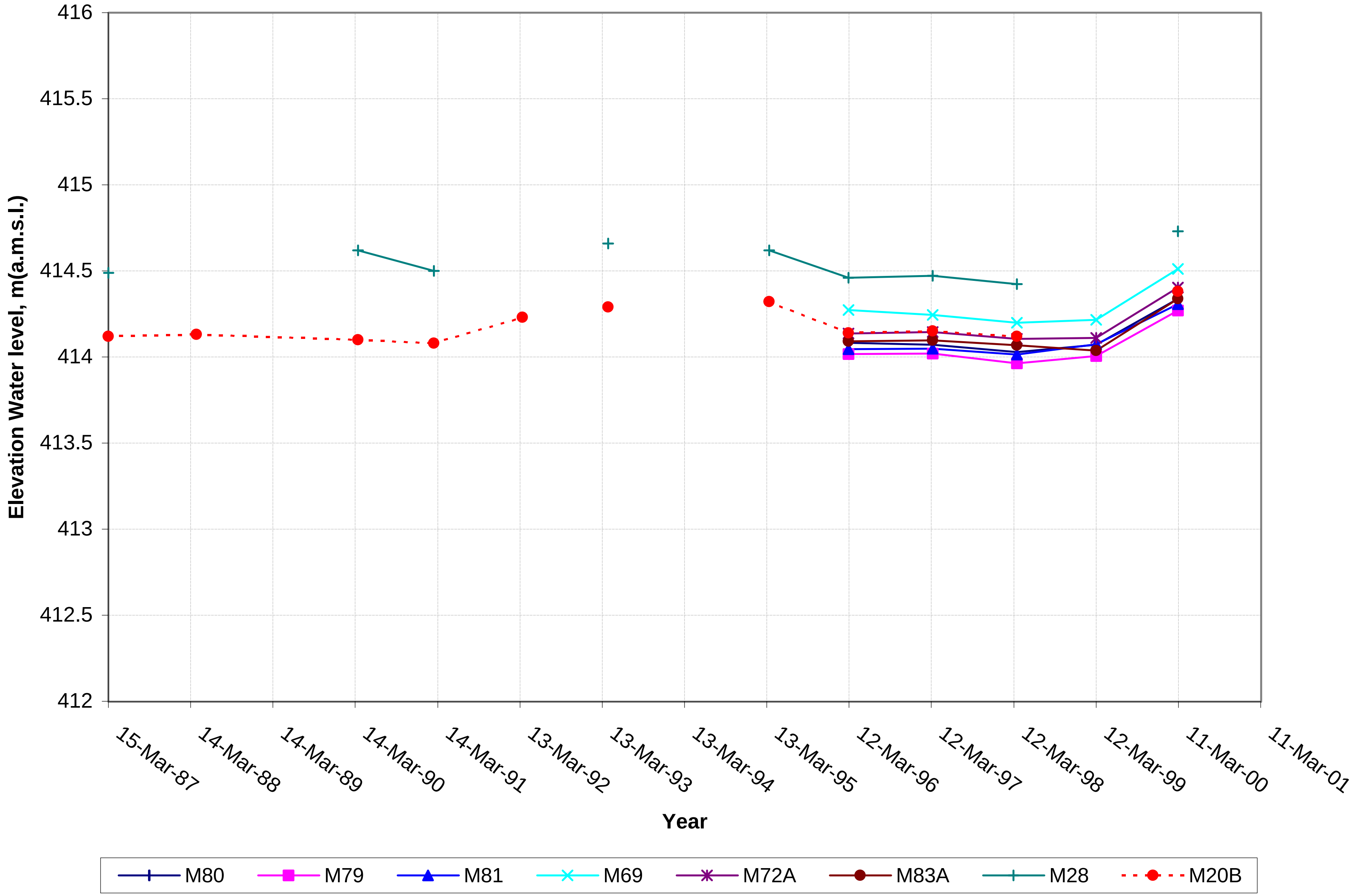


Figure 38. Elevation of water level in March in selected piezometers over period 1987-2000

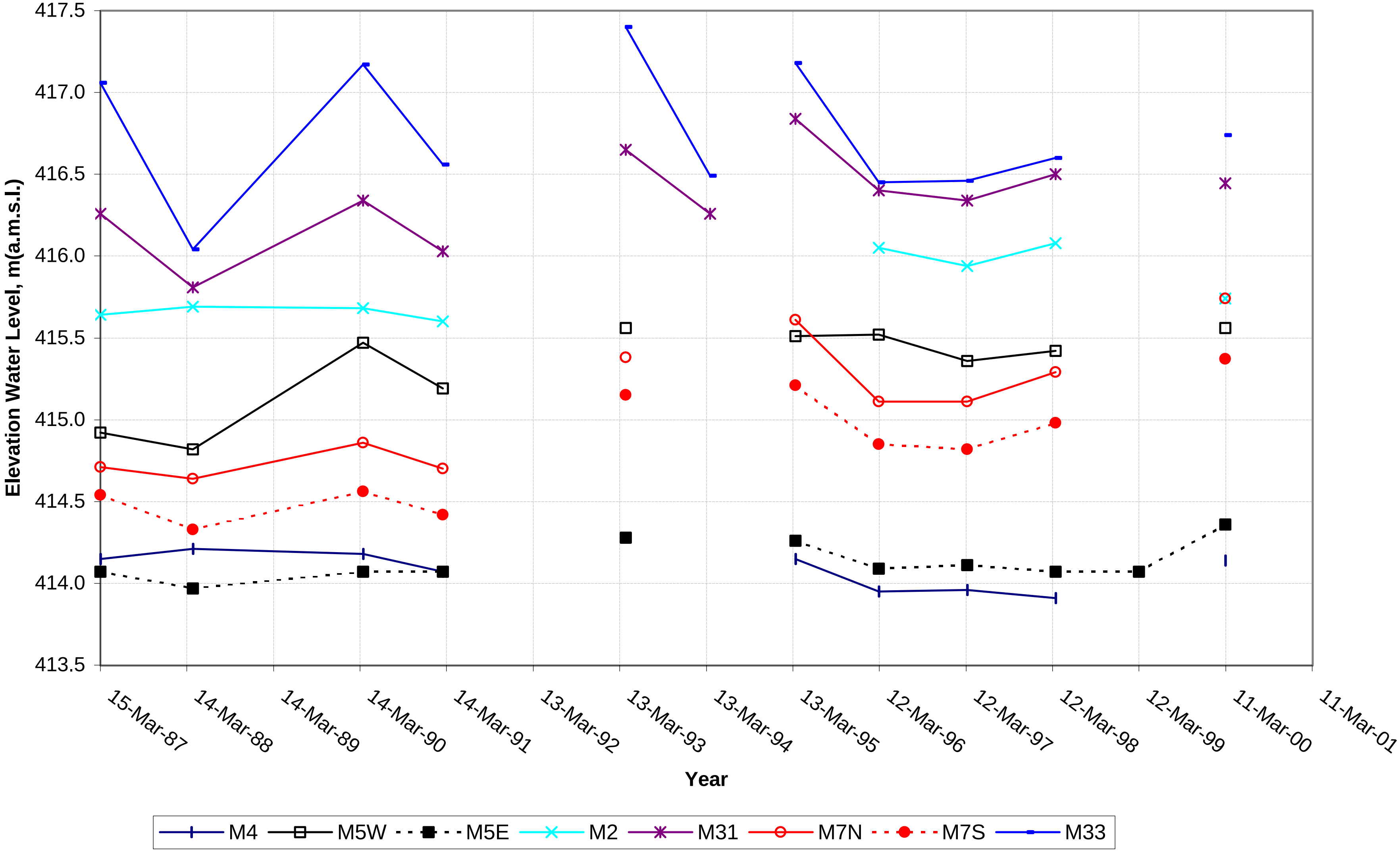


**Figure 39: Elevation of water level in March in piezometers M50 & M54 over period 1987-2000**

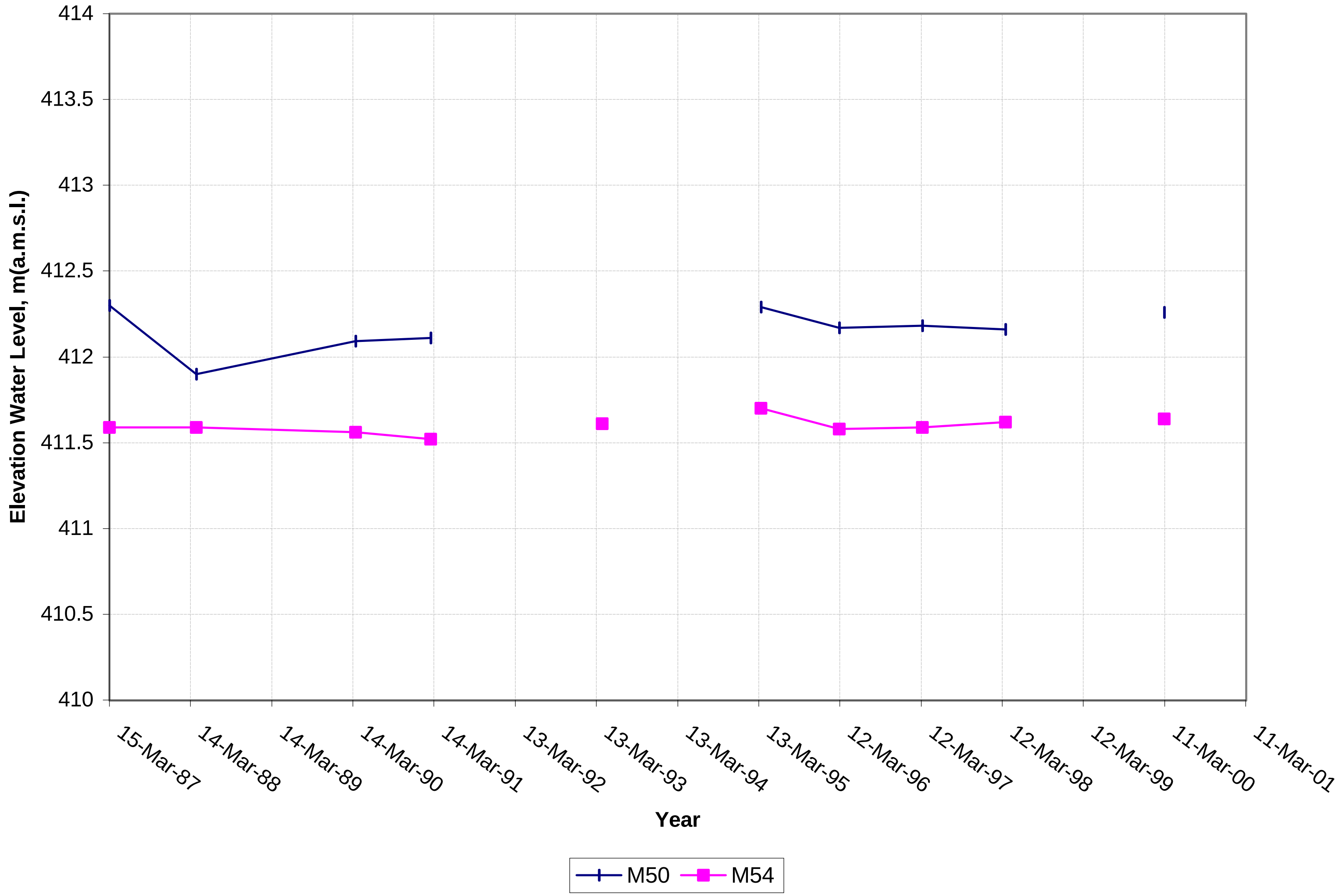
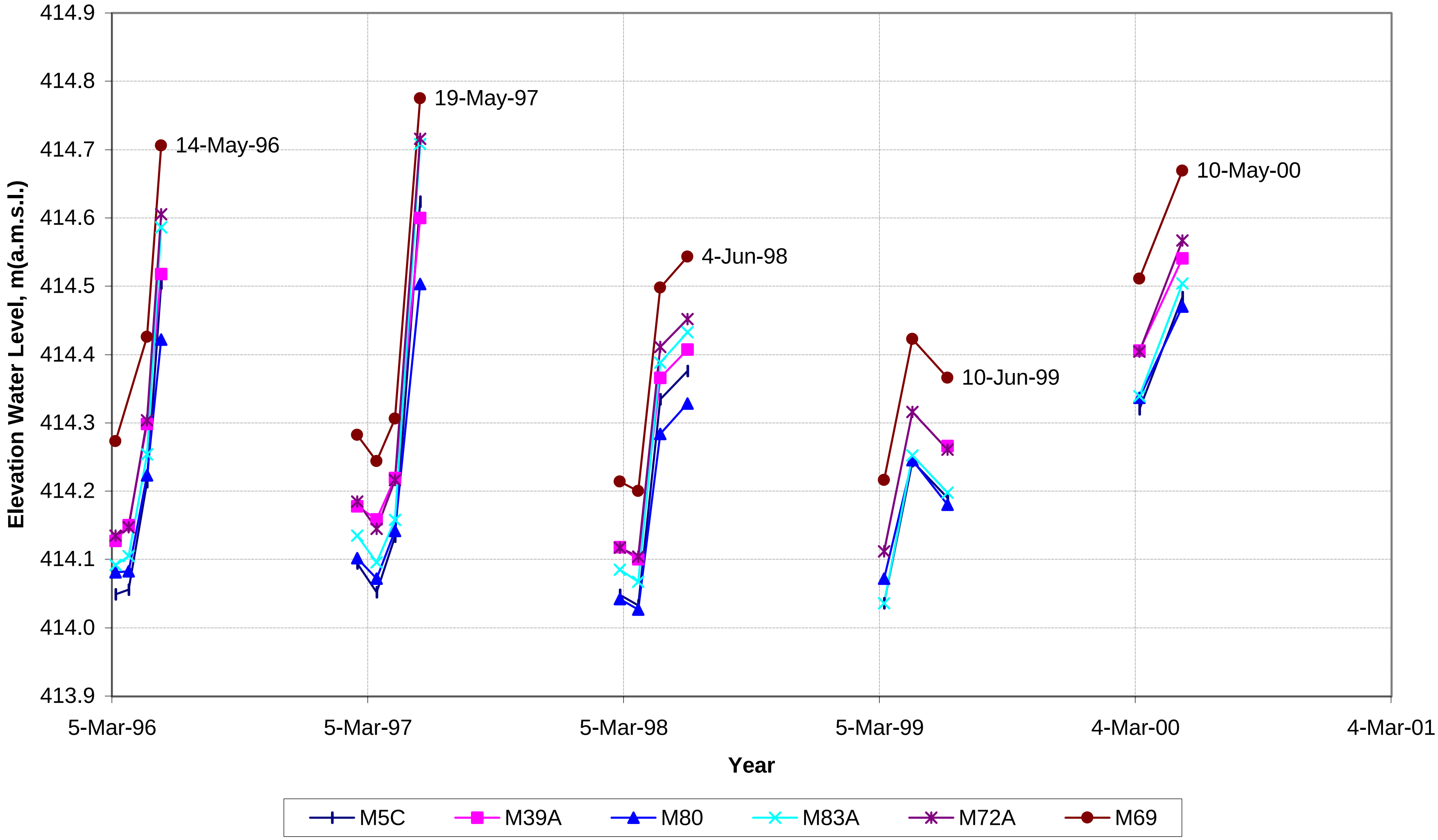


**Figure 40: Elevation of water level in M5C, M39A, M69, M72A, M80 and M83A over period from March-May (1996-2000)**



## Figure 41: Gradient between M69, M72A & M83A and M79 over period from February-May (1996-2000)

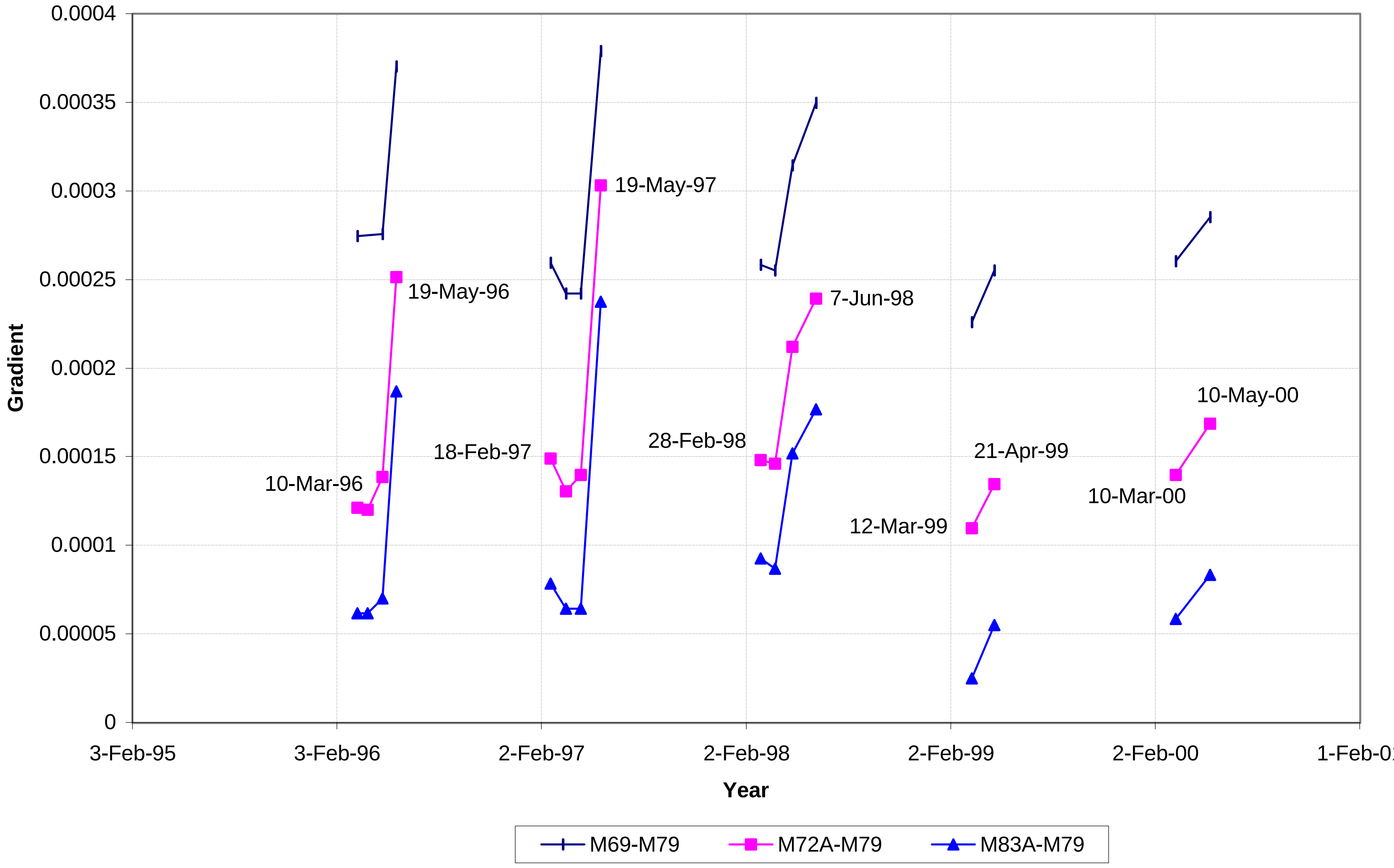


**Figure 42: Gradient between M69, M72A & M83A and M79 in March (dashed) and May (solid) over period 1996-2000**

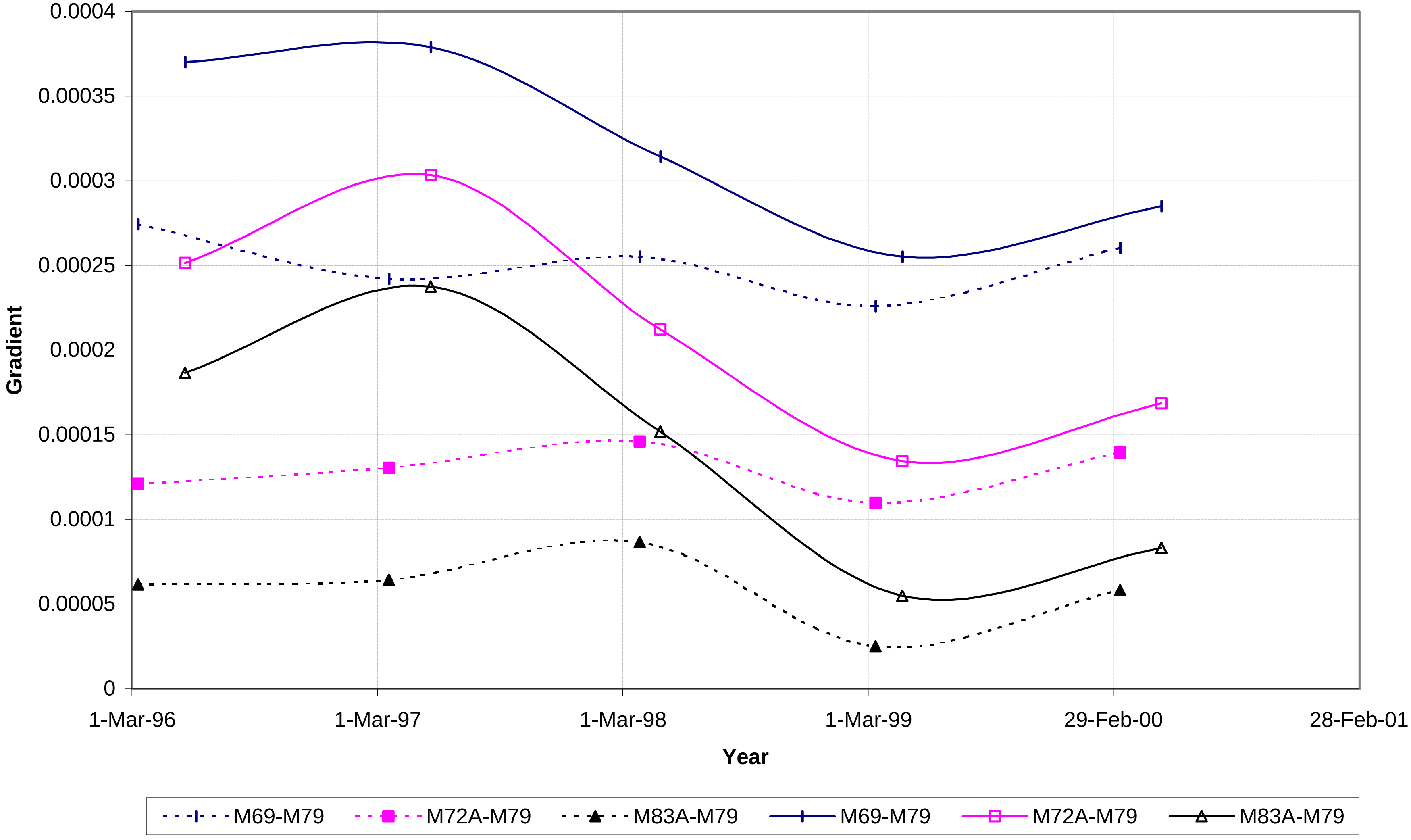


**Figure 43: Elevation of water level in October and March of the following year in piezometers M7S & M7N over period 1986-2000**

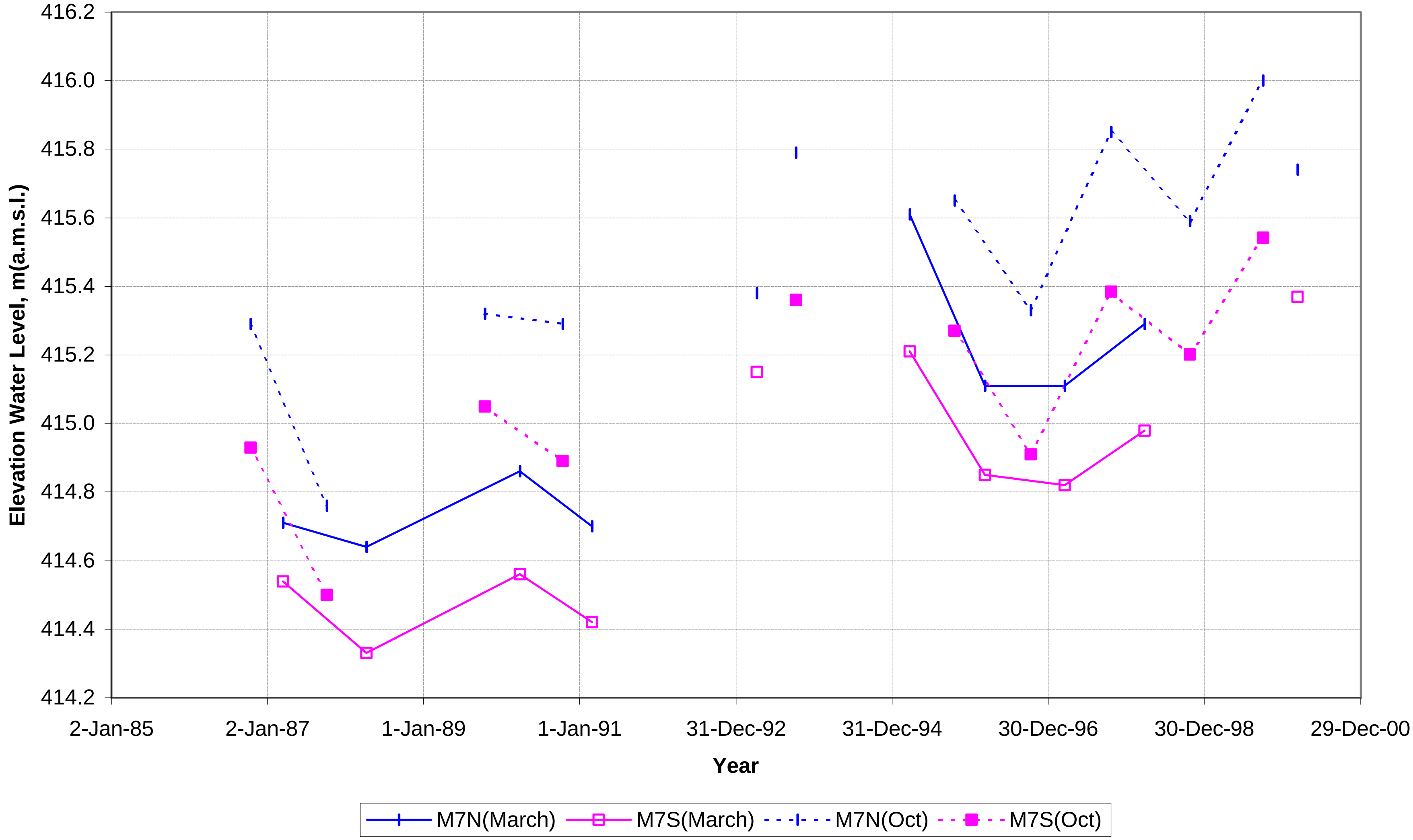


**Figure 44: Elevation of water level in October and March of the following year in piezometers M5W & M5E over period 1986-2000**

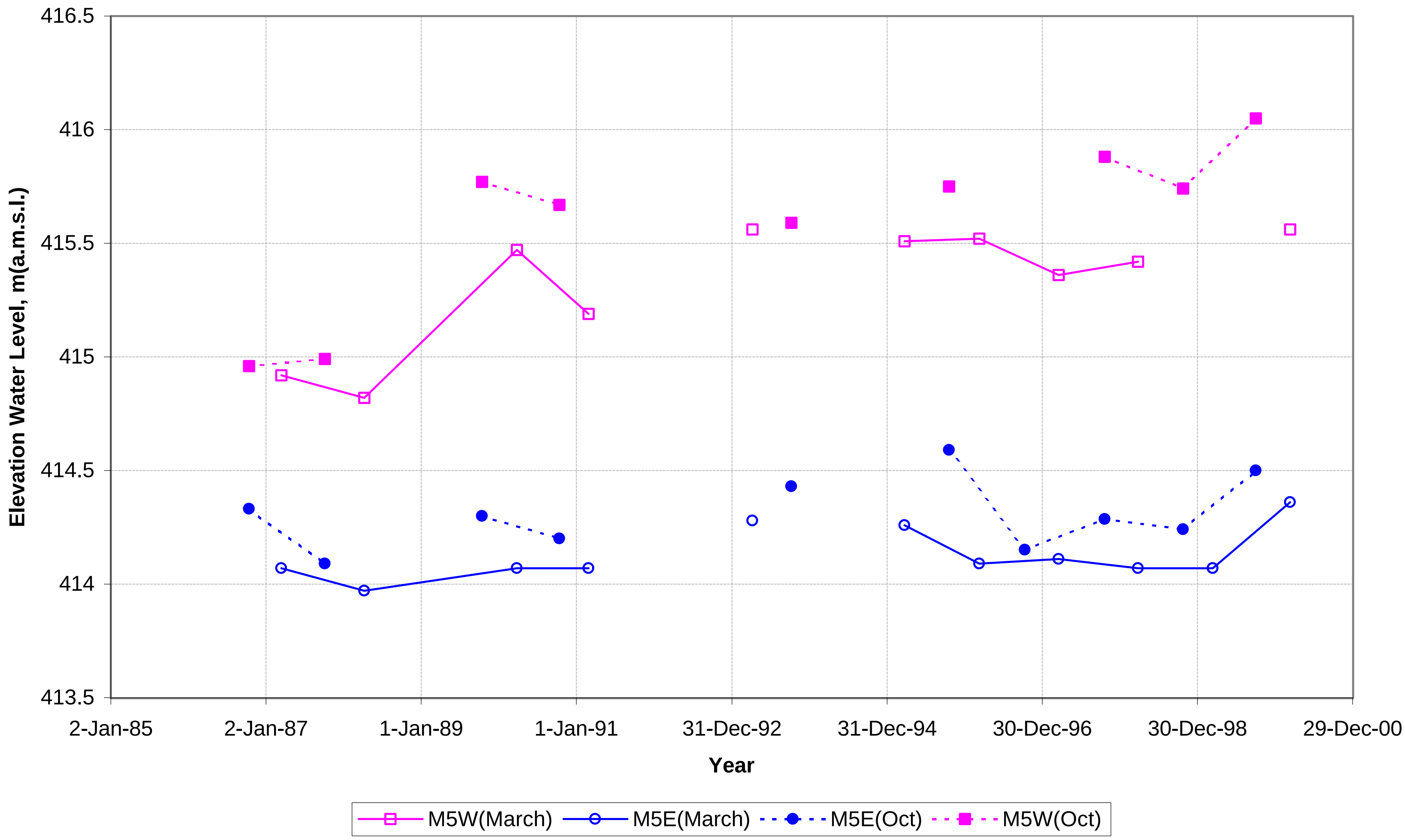


**Figure 45: Total winter precipitation for interval October 1-March 31 (following year),total summer precipitation for interval April 1-September 30 (same year) & total precipitation for interval October1-September 30 (following year) over period 1990-1999**

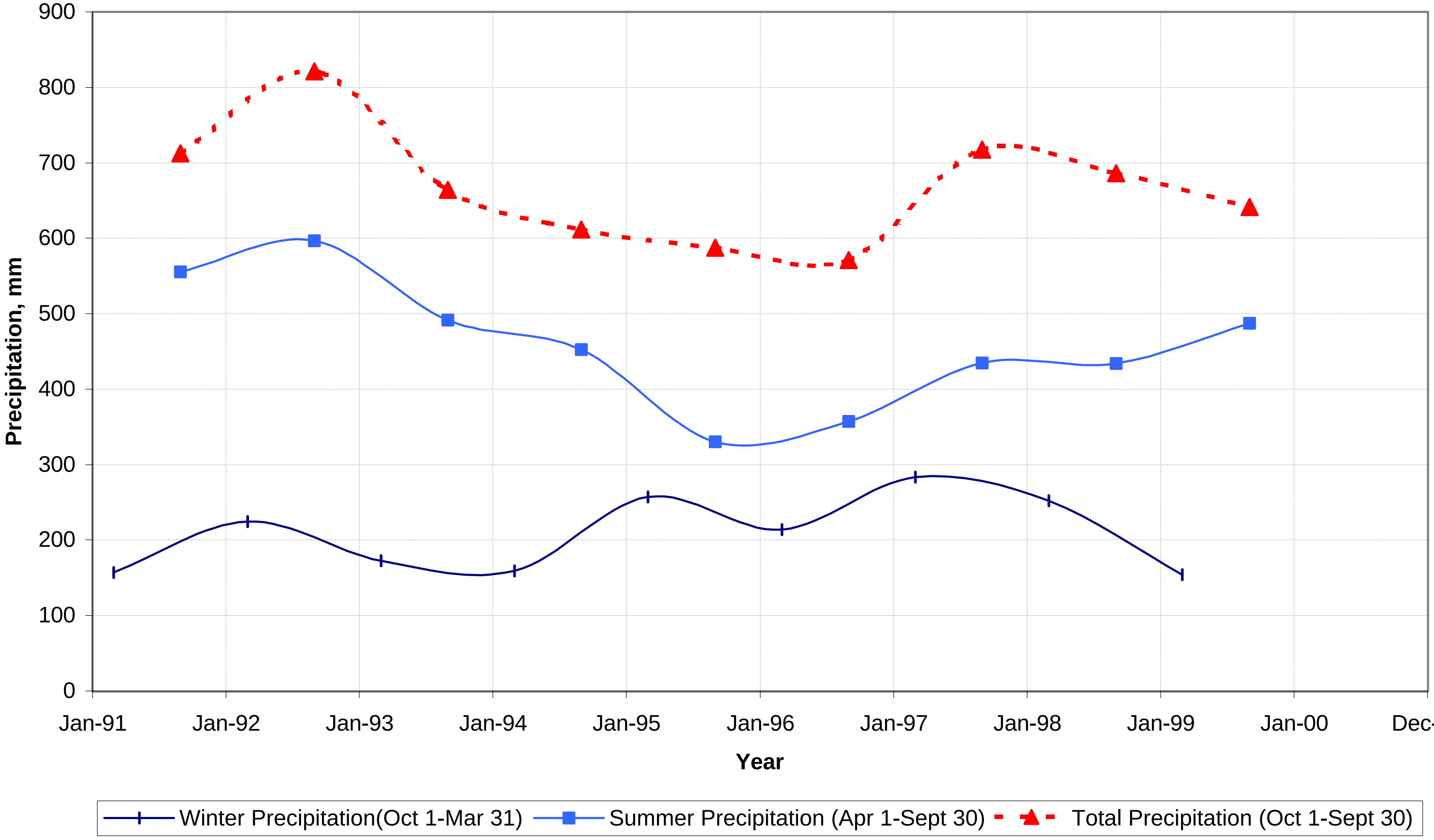


**Figure 46: Total winter precipitation (Oct. 1-Mar 31), total summer precipitation (Apr.1-Sept. 30) & Total precipitation and elevation of water level in piezometers M5E & W and M7N in October over period 1990-1999**

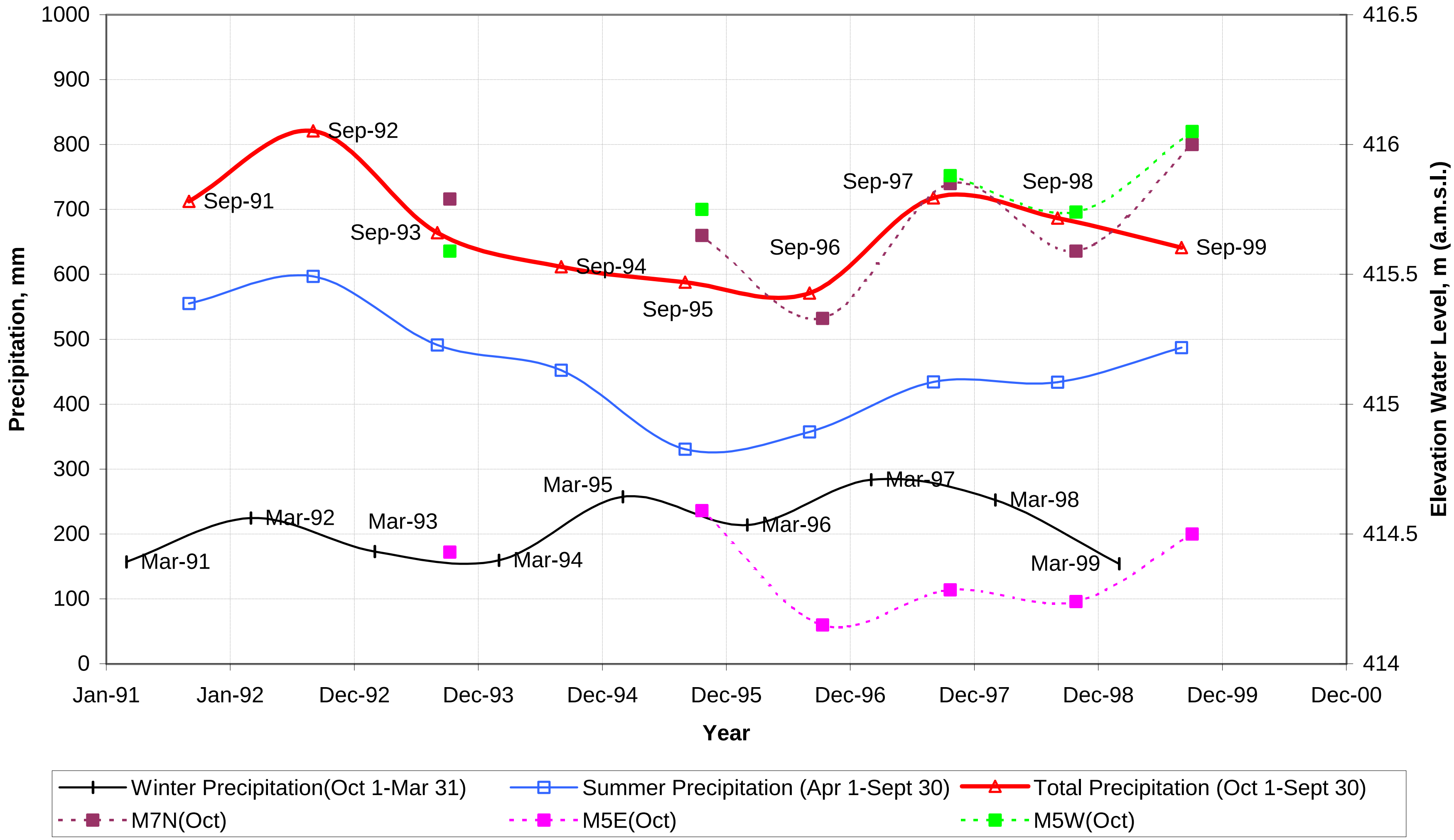


**Figure 47: Elevation of Water Level in a Selected Number of Piezometers in the SANDPIT AREA from September, 1997 to August, 1998**

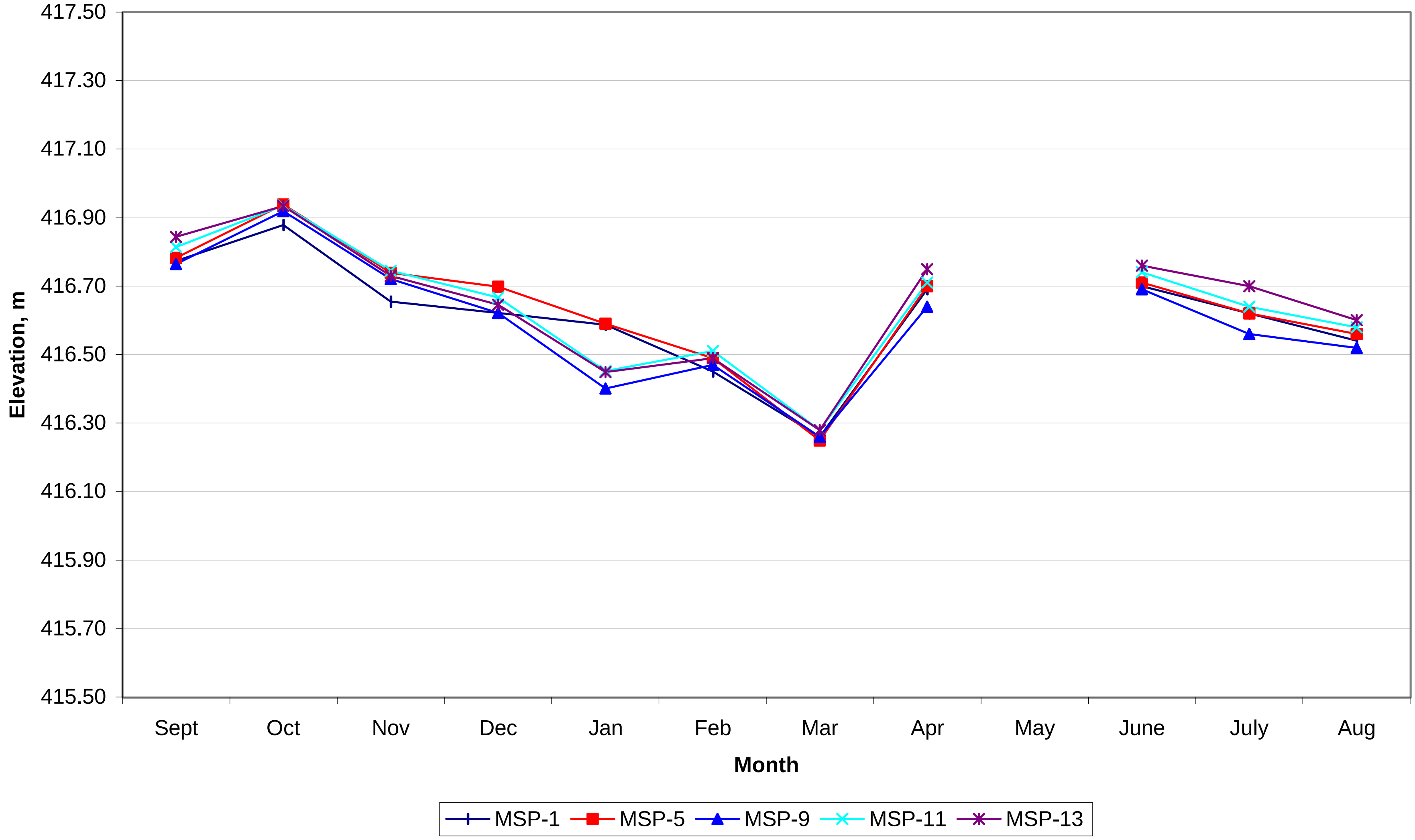
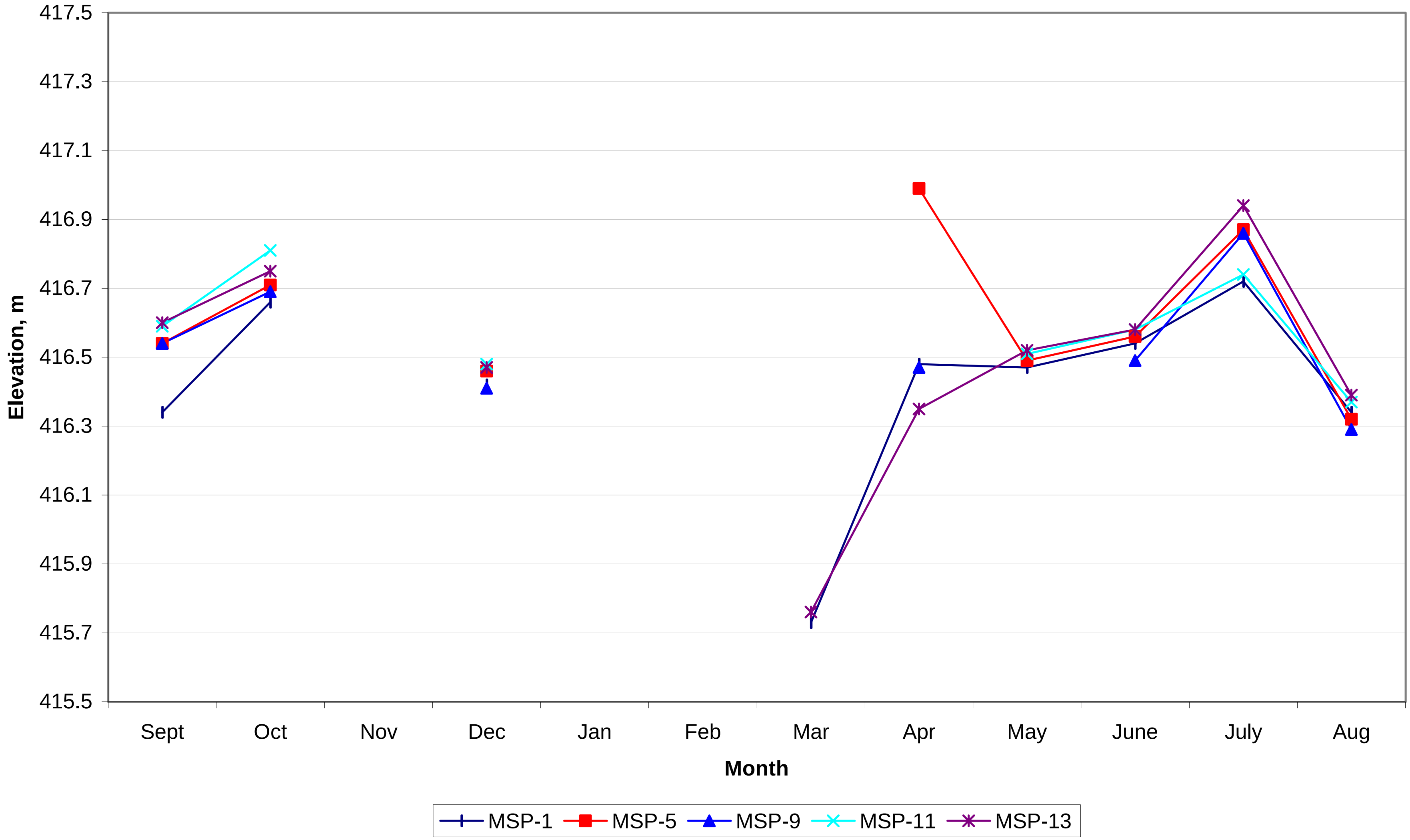


**Figure 48: Elevation of Water Level in a Selected Number of Piezometers in the SANDPIT AREA from September, 1998 to August, 1999**



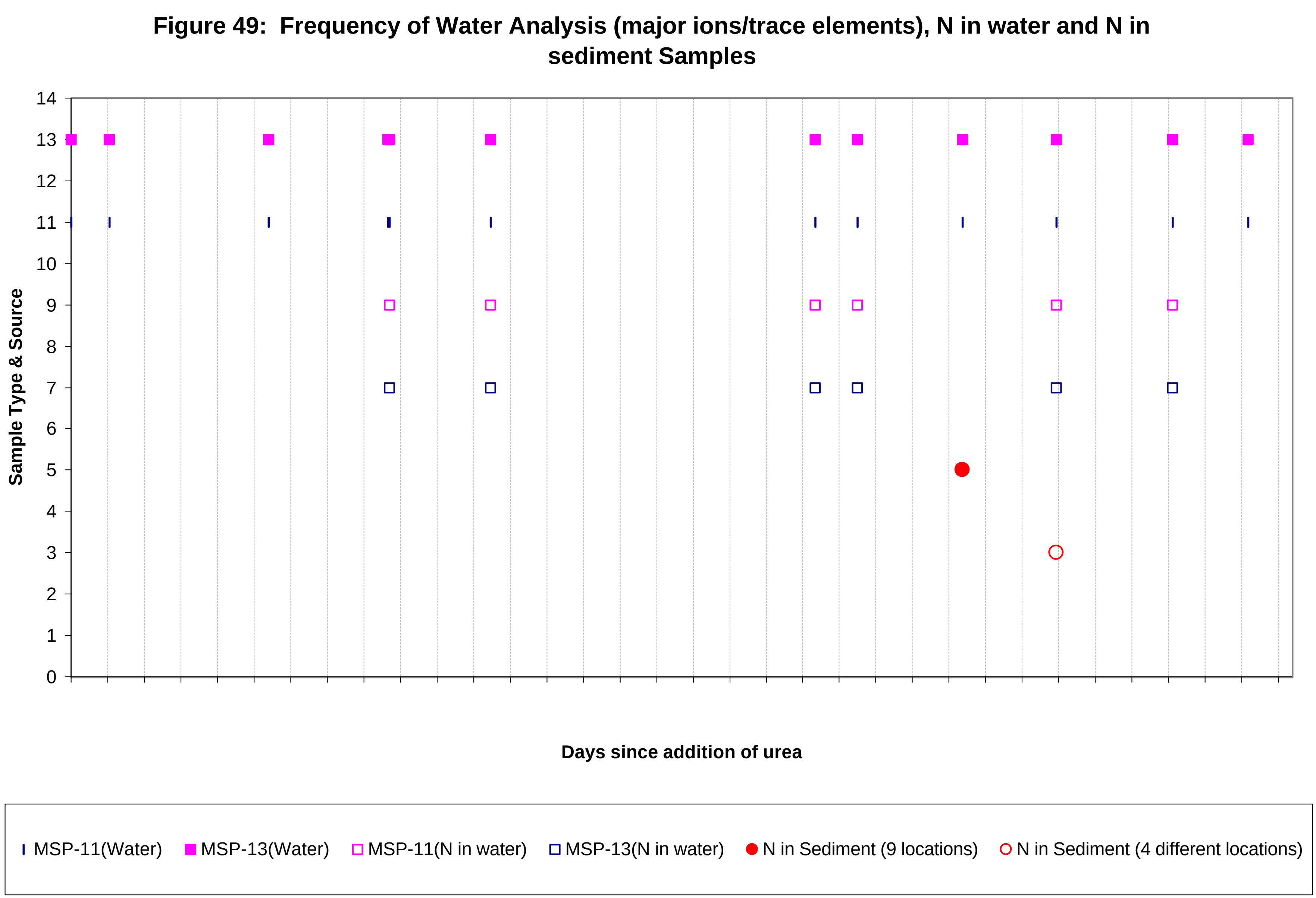


Figure 49: Frequency of Water Analysis (major ions/trace elements), N in water and N in sediment Samples
Sample Type & Source
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
Days since addition of urea
MSP-11(Water)
MSP-13(Water)
MSP-11(N in water)
MSP-13(N in water)
N in Sediment (9 locations)
N in Sediment (4 different locations)

**Figure 50: TKN, $NH_3$ & $NO_3$ in Water from Piezometers for 2 Different Dates: 06/27/1999 & 12/07/1999**

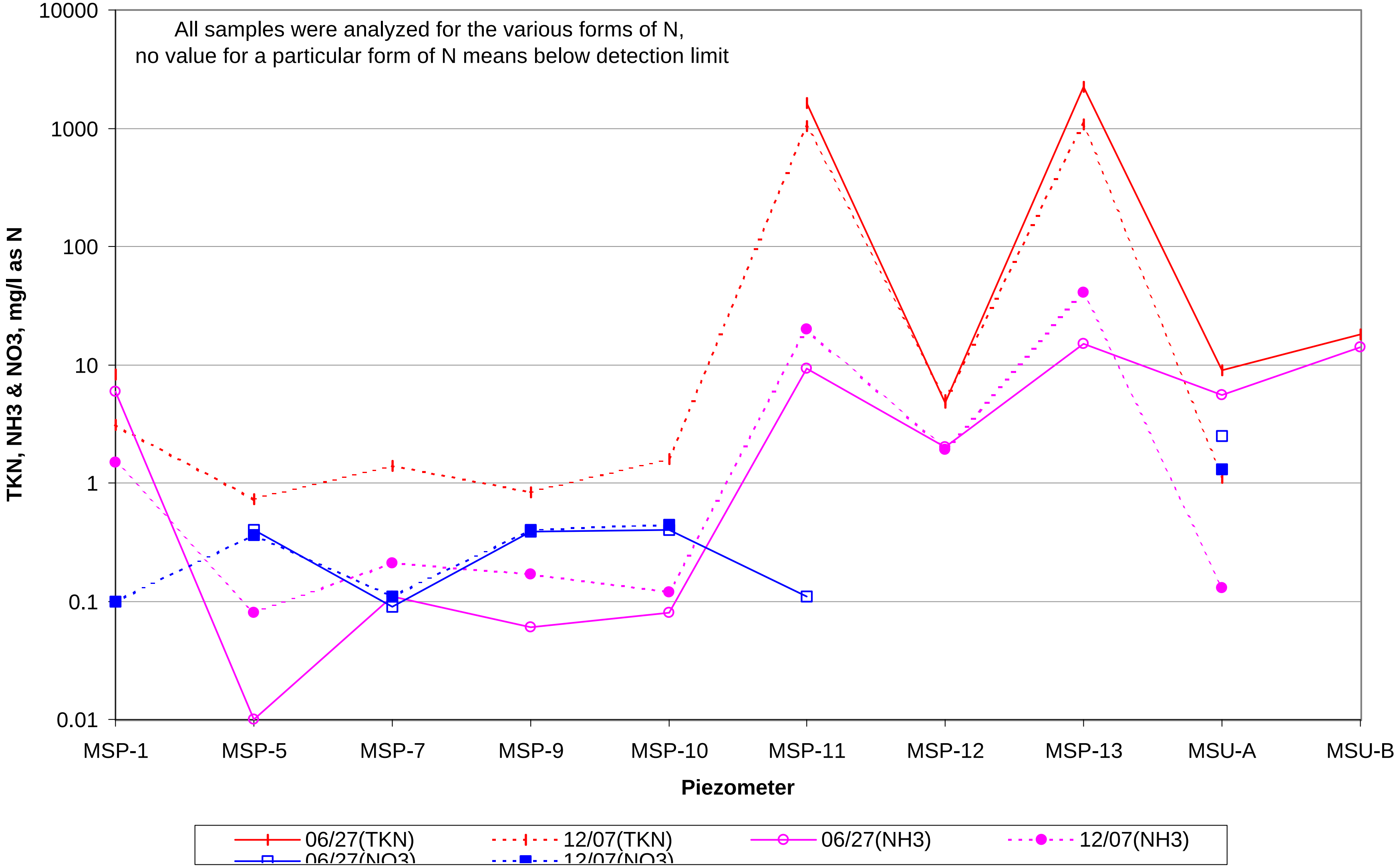


**Figure 51: TKN & NH3 in Water versus time: Piezometers MSP-11 and MSP-13**

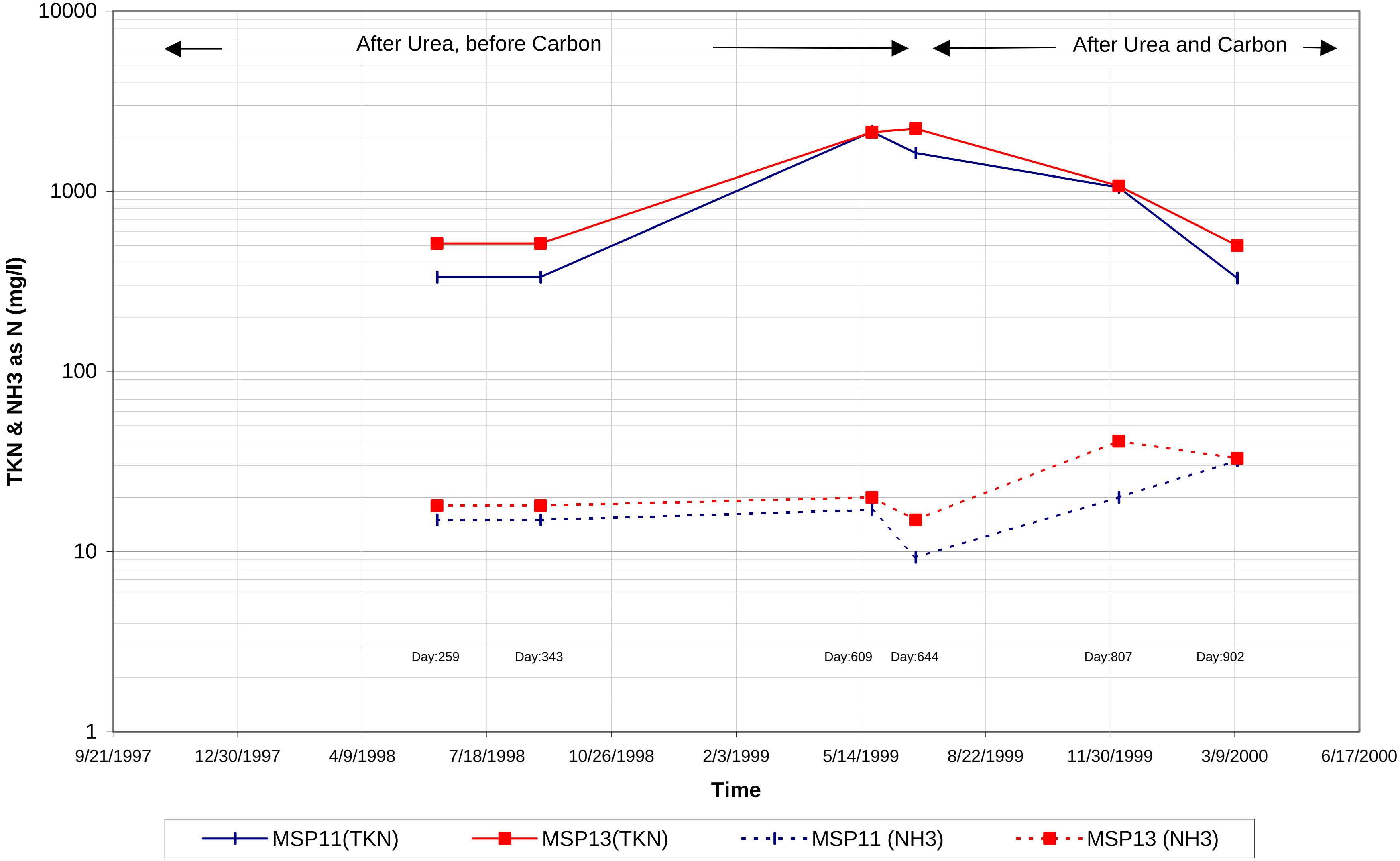


Figure 51a:  TKN & NH3 in Water versus time: Piezometers MSP-11 and MSP-13

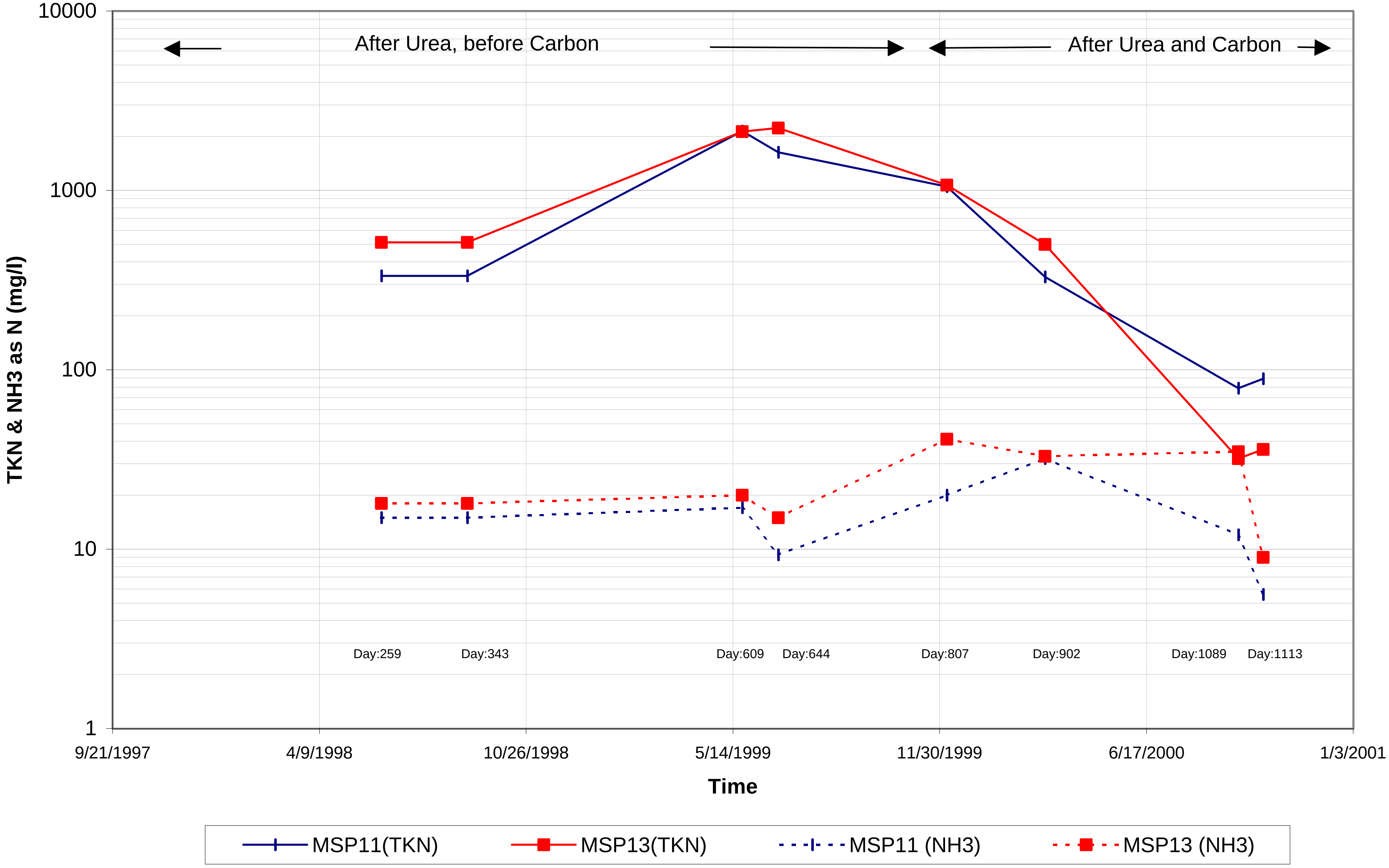
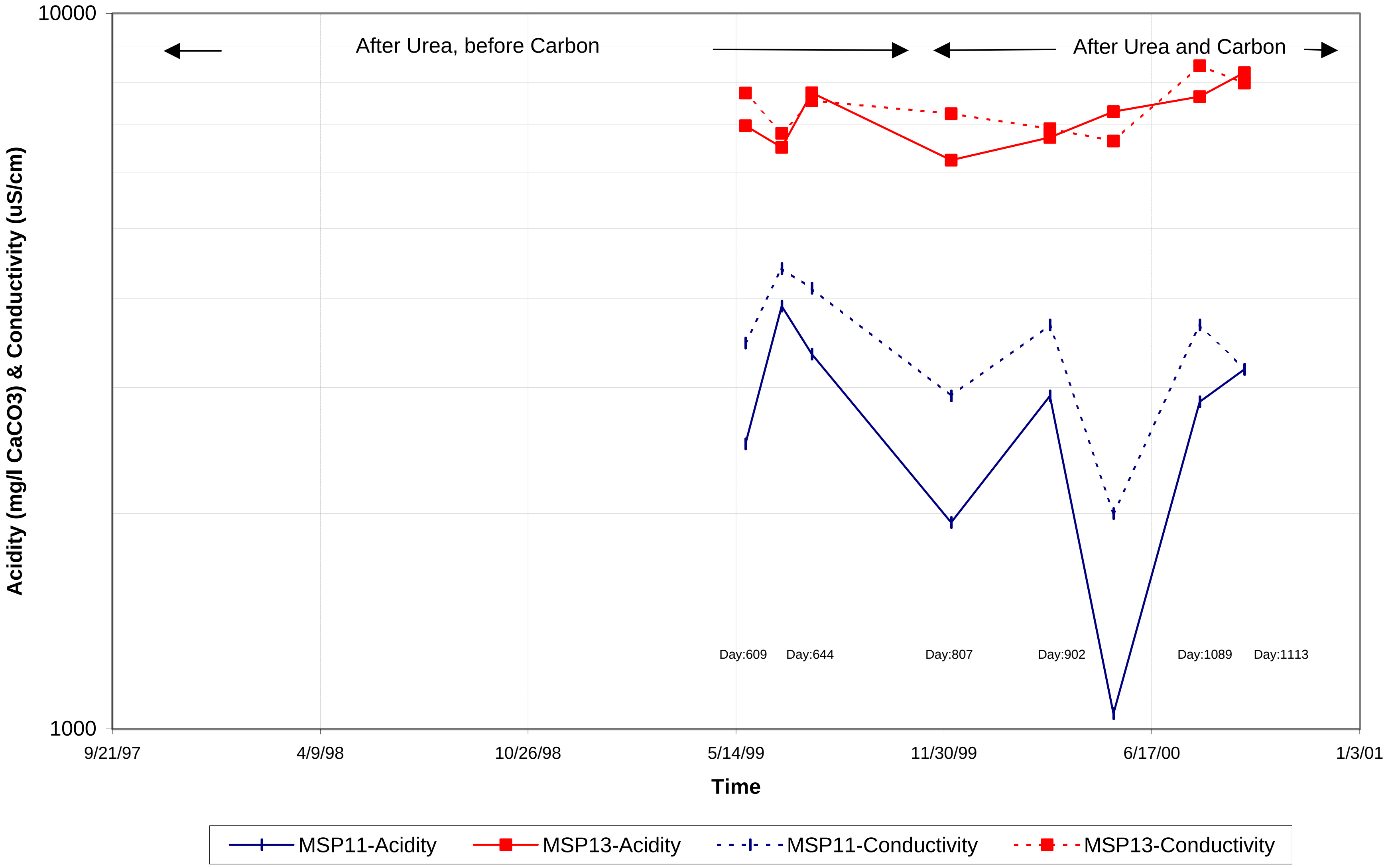


**Figure 52: Acidity & Conductivity vs time: Piezometers MSP-11 and MSP-13 (after bailing)**



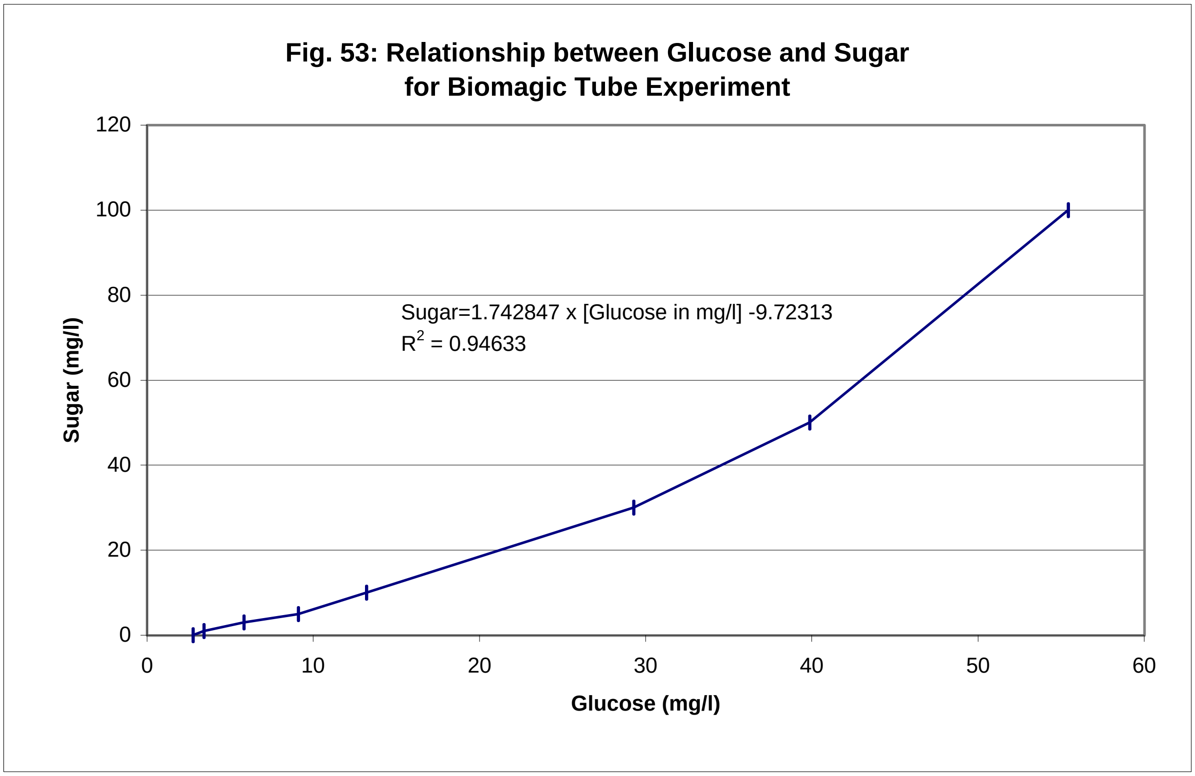


Fig. 53: Relationship between Glucose and Sugar
for Biomagic Tube Experiment
Sugar (mg/l)
120
100
80
60
40
20
0
0
10
20
30
40
50
60
Glucose (mg/l)
Sugar=1.742847 x [Glucose in mg/l] -9.72313
R2 = 0.94633

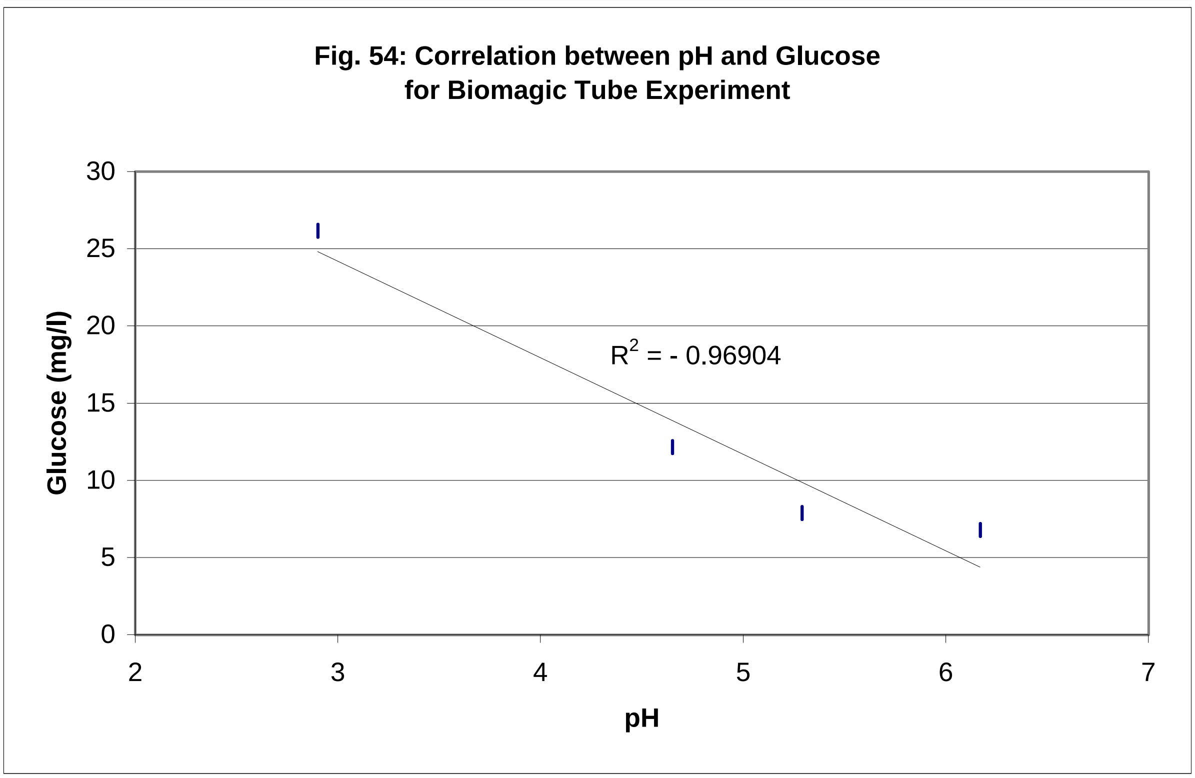
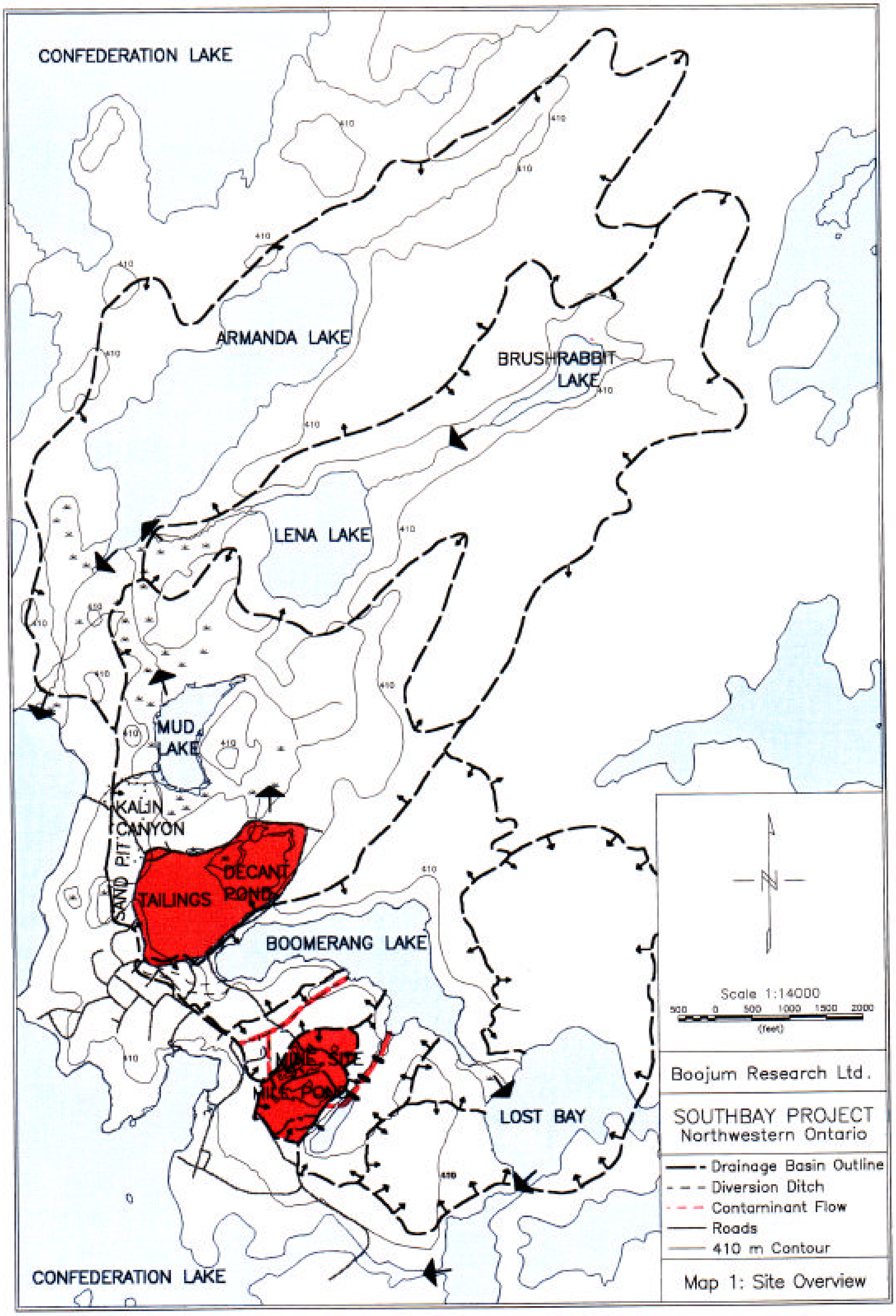
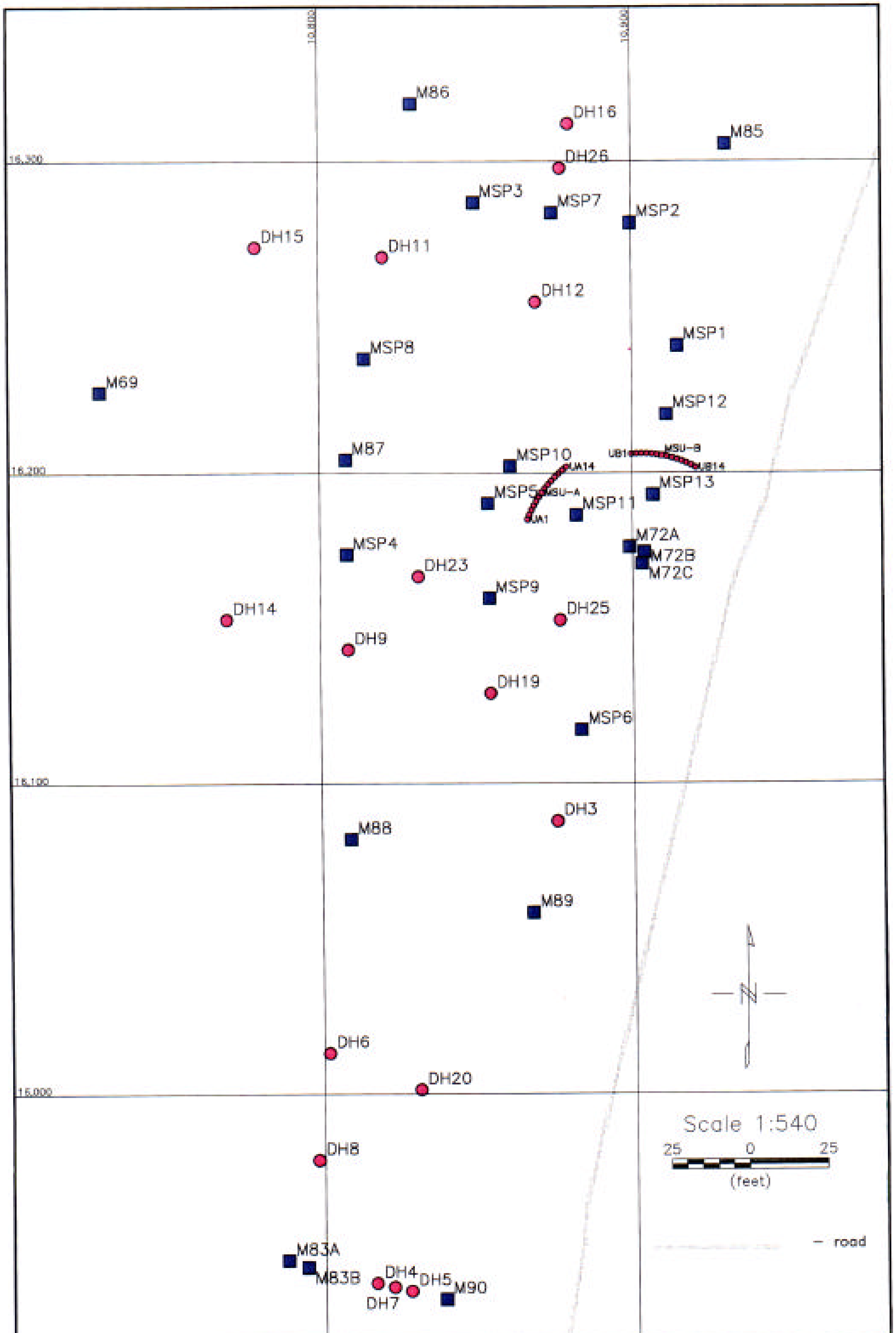


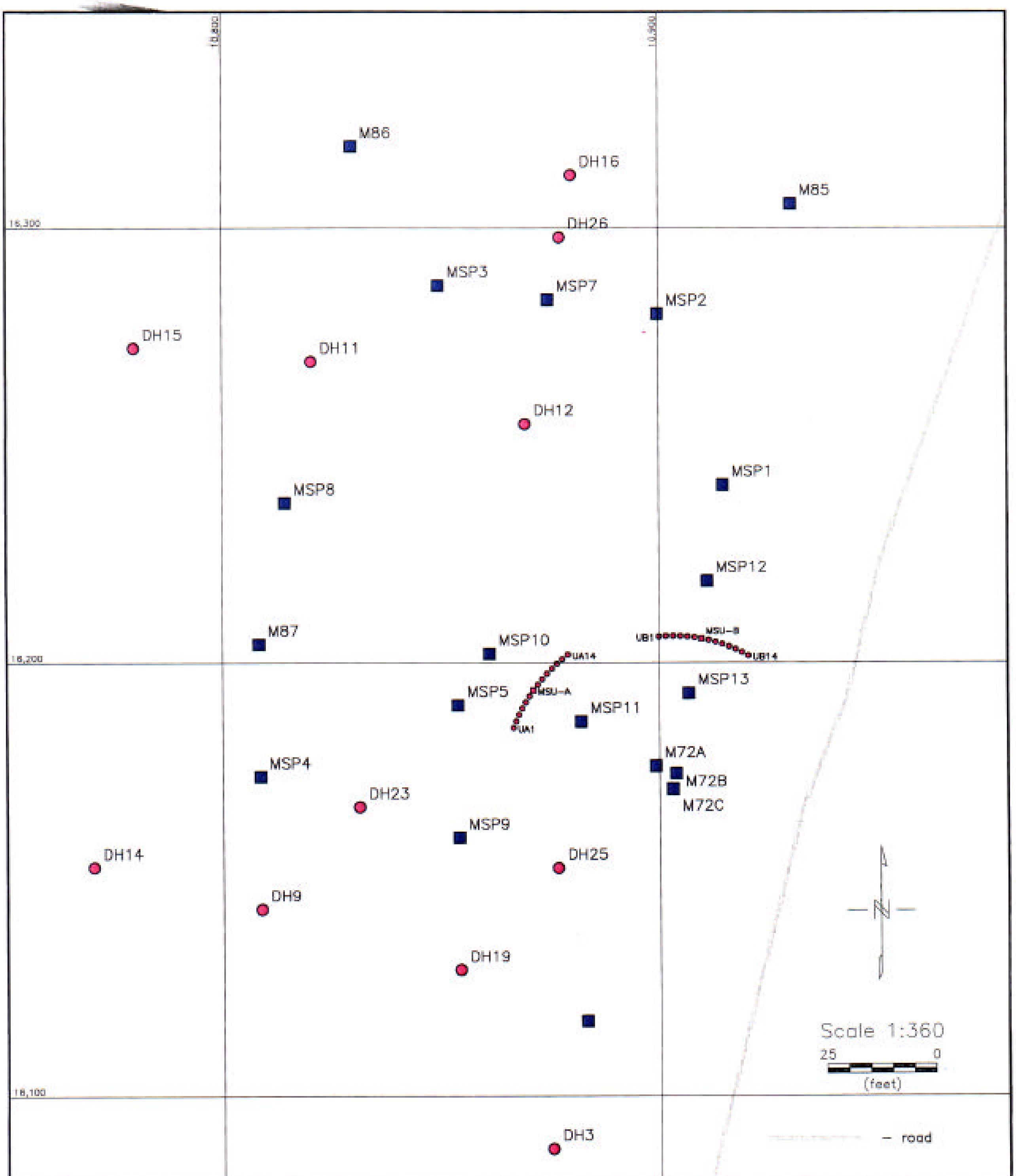
Fig. 54: Correlation between pH and Glucose
for Biomagic Tube Experiment
Glucose (mg/l)
30
25
20
15
10
5
0
2
3
4
5
6
7
pH
R2 = - 0.96904


CONFEDERATION LAKE
ARMANDA LAKE
BRUSHRABBIT LAKE
LENA LAKE
MUD LAKE
KALIN CANYON
SAND PIT
TAILINGS
DECANT POND
BOOMERANG LAKE
MINE SITE
MILL POND
LOST BAY
CONFEDERATION LAKE
410
Scale 1:14000
500 0 500 1000 1500 2000
(feet)
Boojum Research Ltd.
SOUTHBAY PROJECT
Northwestern Ontario
Drainage Basin Outline
Diversion Ditch
Contaminant Flow
Roads
410 m Contour
Map 1: Site Overview



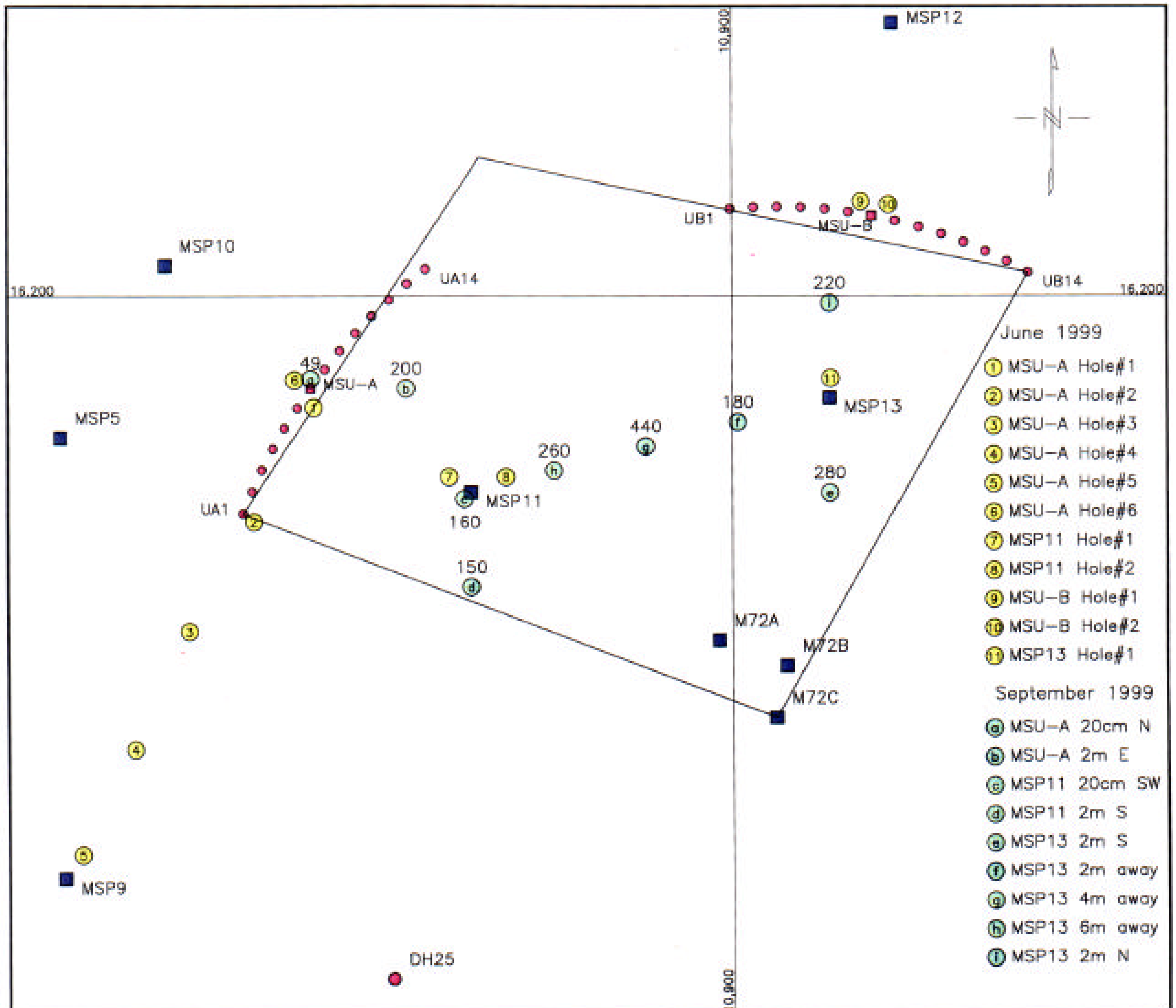

Map 2a: Location of all Piezometers and Drill Holes, September 1997

■ – Piezometer ● – Drill Hole




Map 2b: Location of Piezometers and Drill Holes in the Vicinity of Urea Application

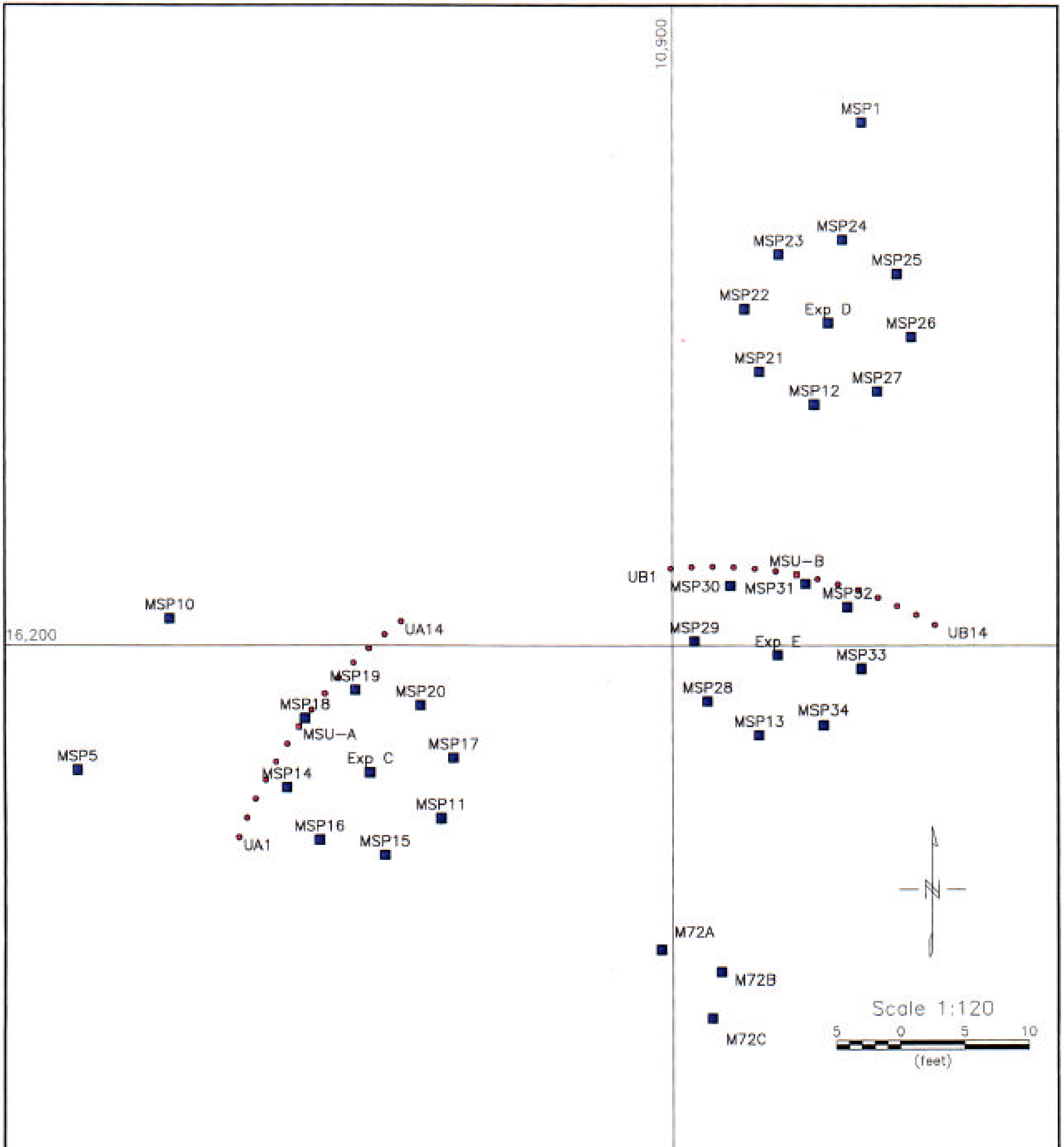
■ – Piezometer ● – Drill Hole




Map 3: Soil Samples Location and [TKN] (ug/g) in soil samples, September 1999 Scale 1:120

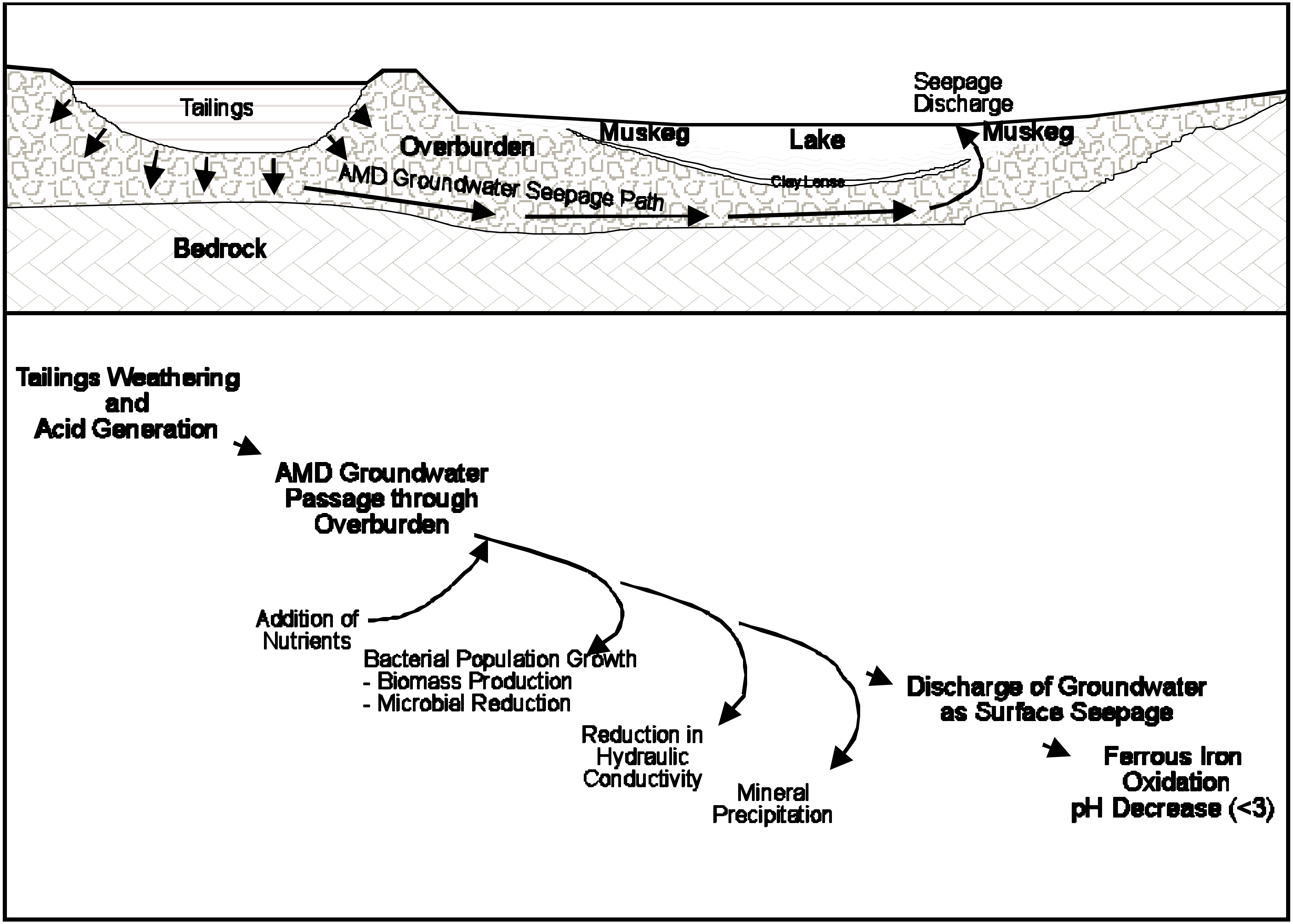
■ – Piezometer ● – Drill Hole ① ⓐ – Urea Test Hole

5 0 5 10 (feet)

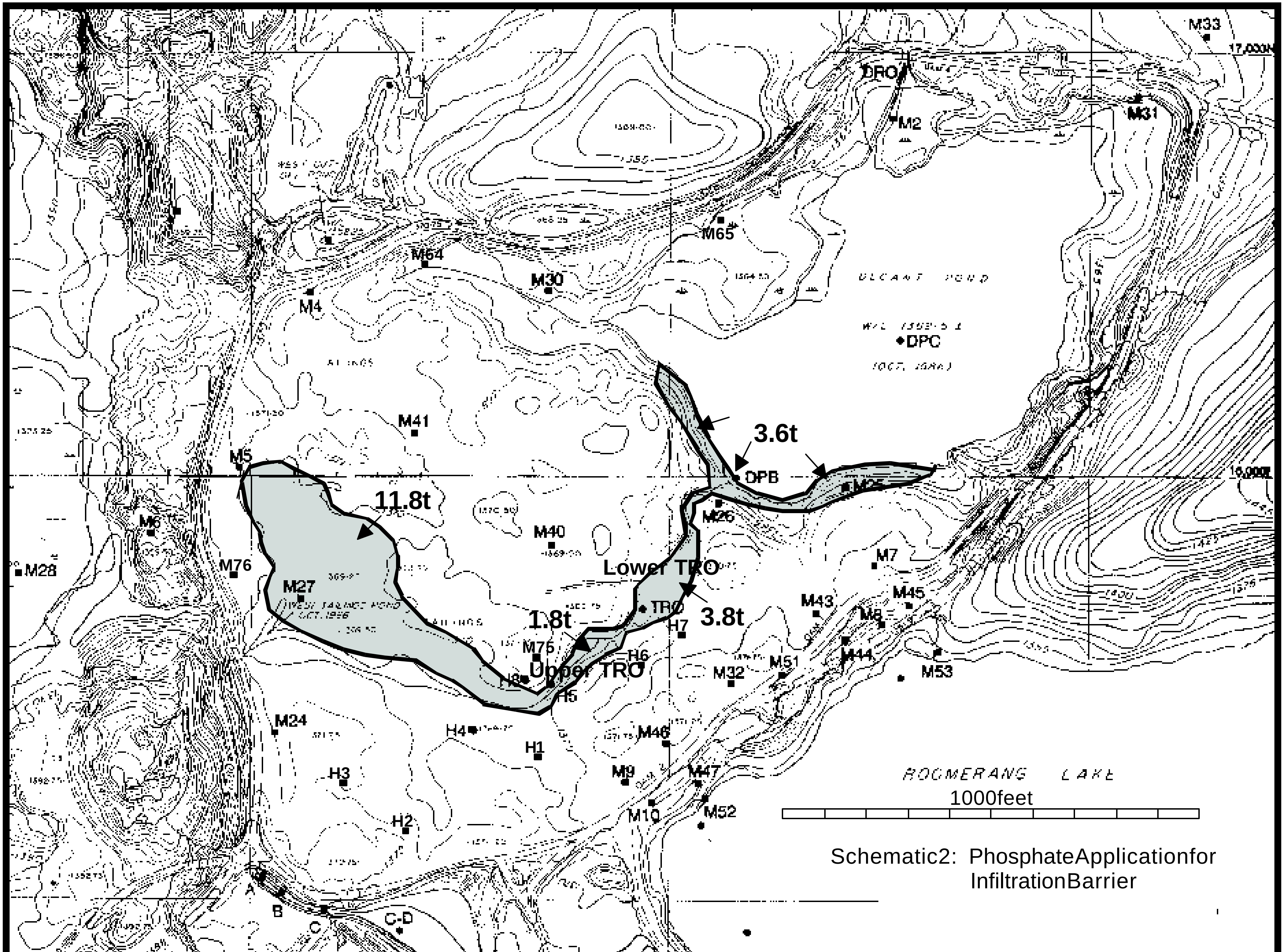



Map 4: Location of New Piezometers, October 2000

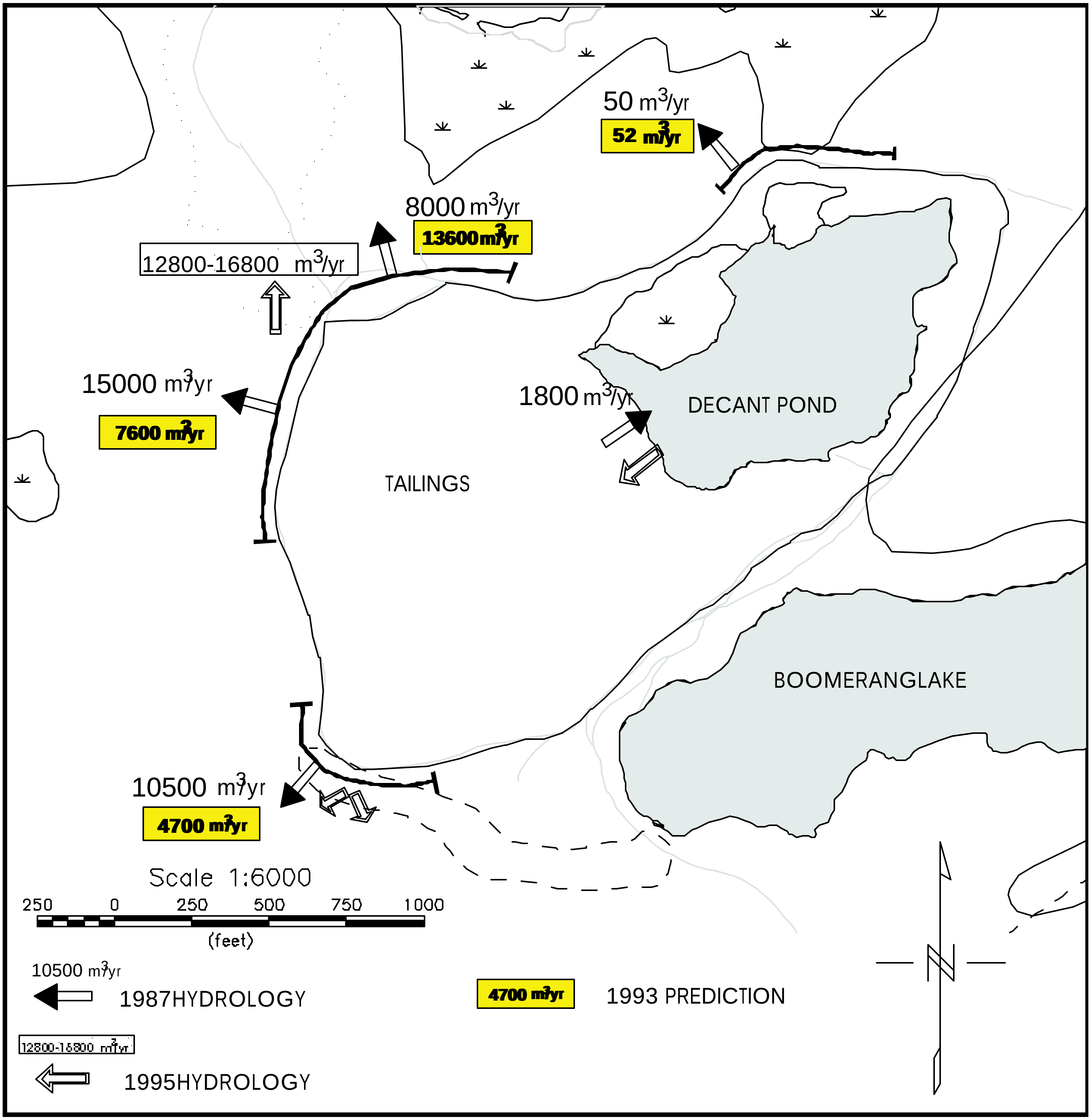
■ – Piezometer ● – Drill Hole



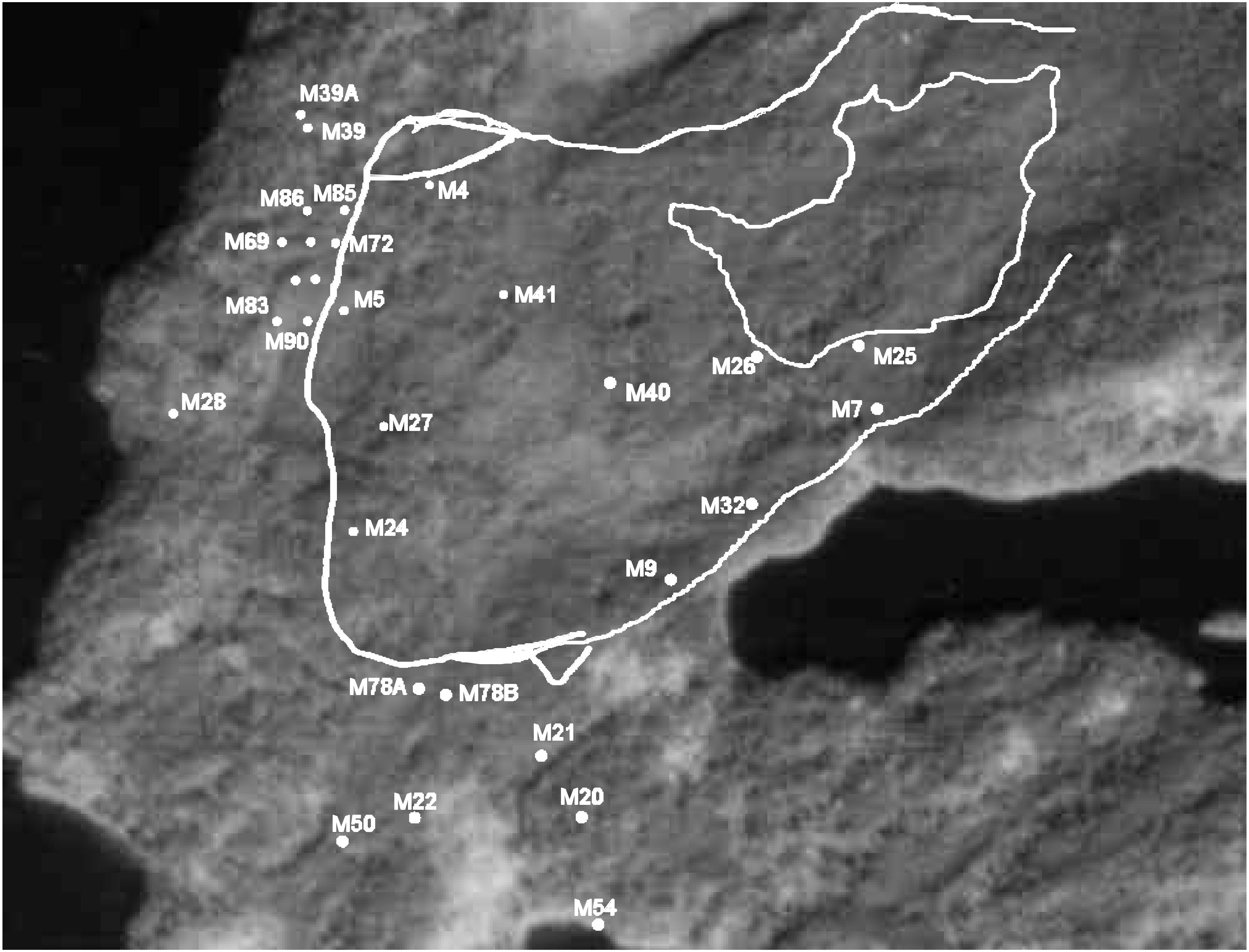

Schematic 1: Concept of in-situ treatment




Schematic2: PhosphateApplicationfor InfiltrationBarrier

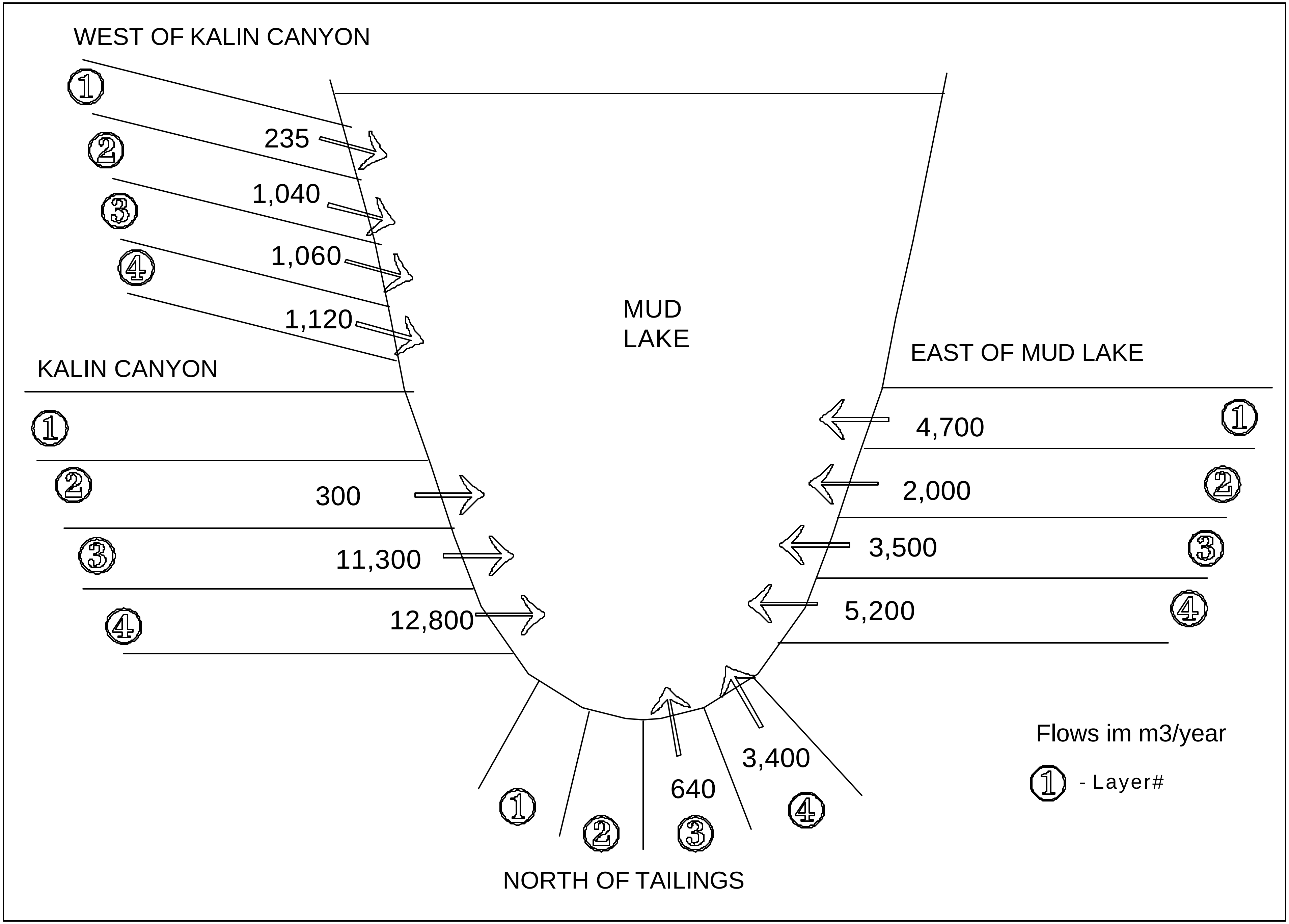



Schematic 3: Hydrological Balances of Tailings Basin, 1987-1995

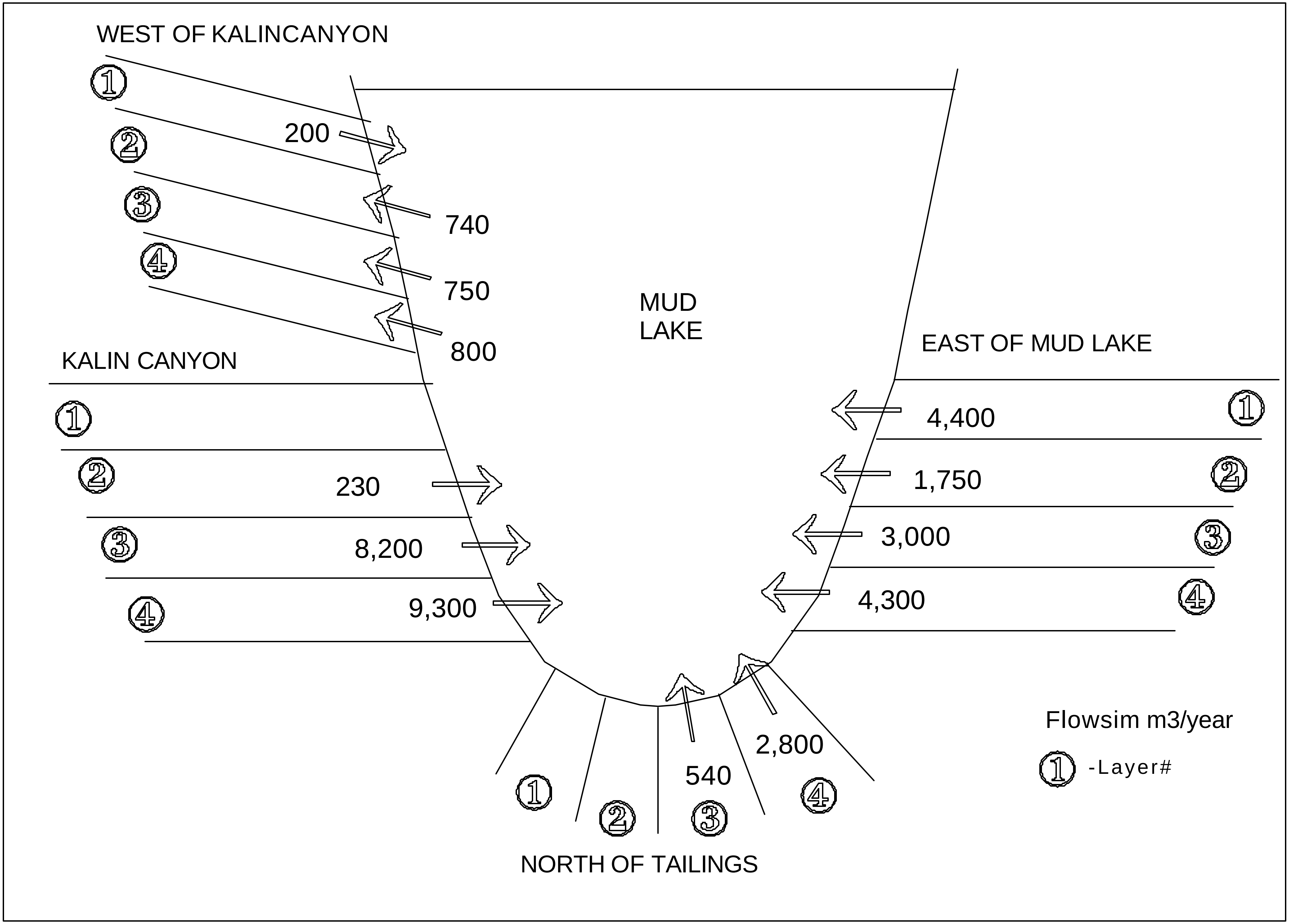


M39A
M39
M4
M86
M85
M69
M72
M41
M83
M5
M90
M26
M25
M28
M40
M7
M27
M32
M24
M9
M78A
M78B
M21
M20
M22
M50
M54

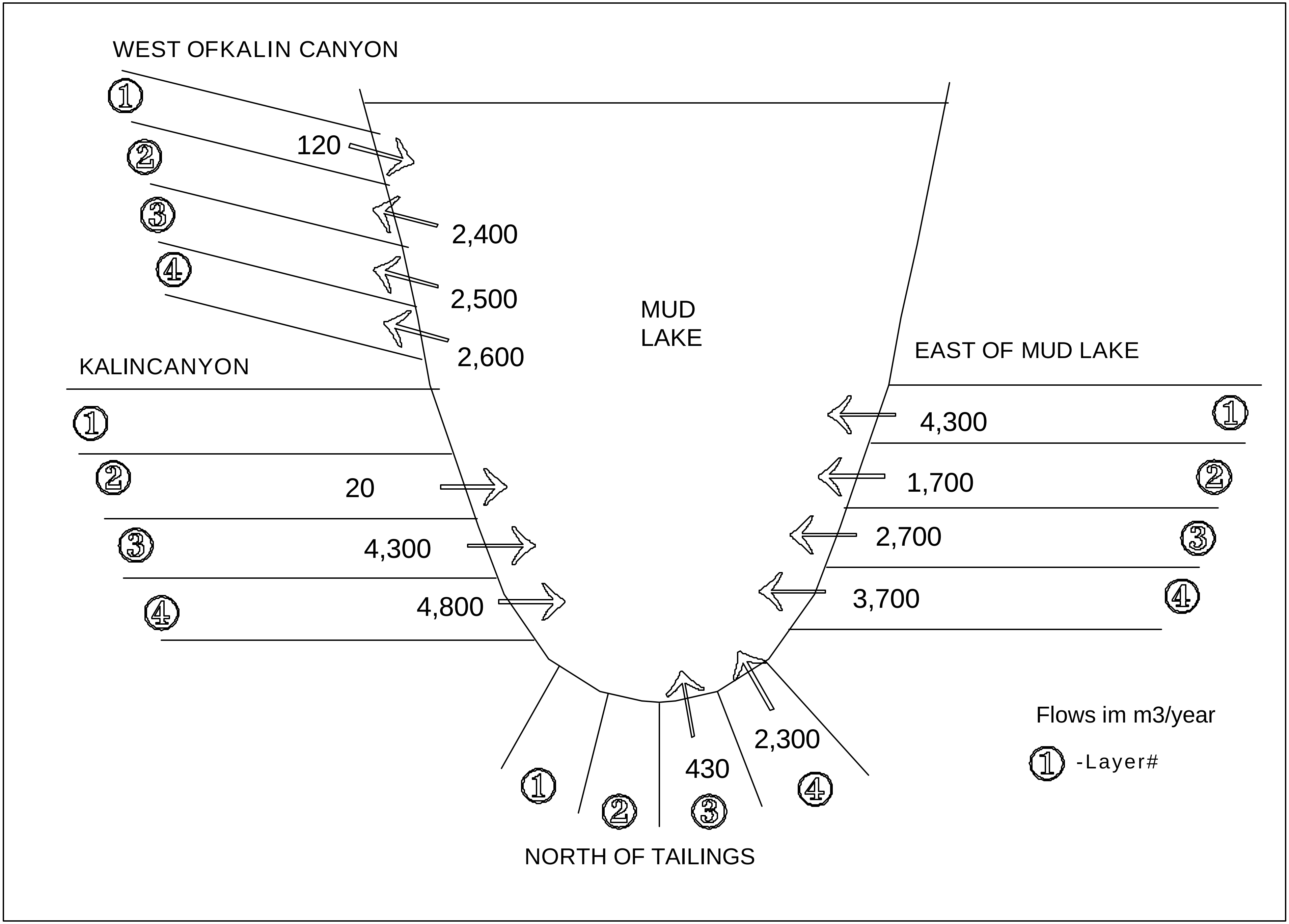
S5



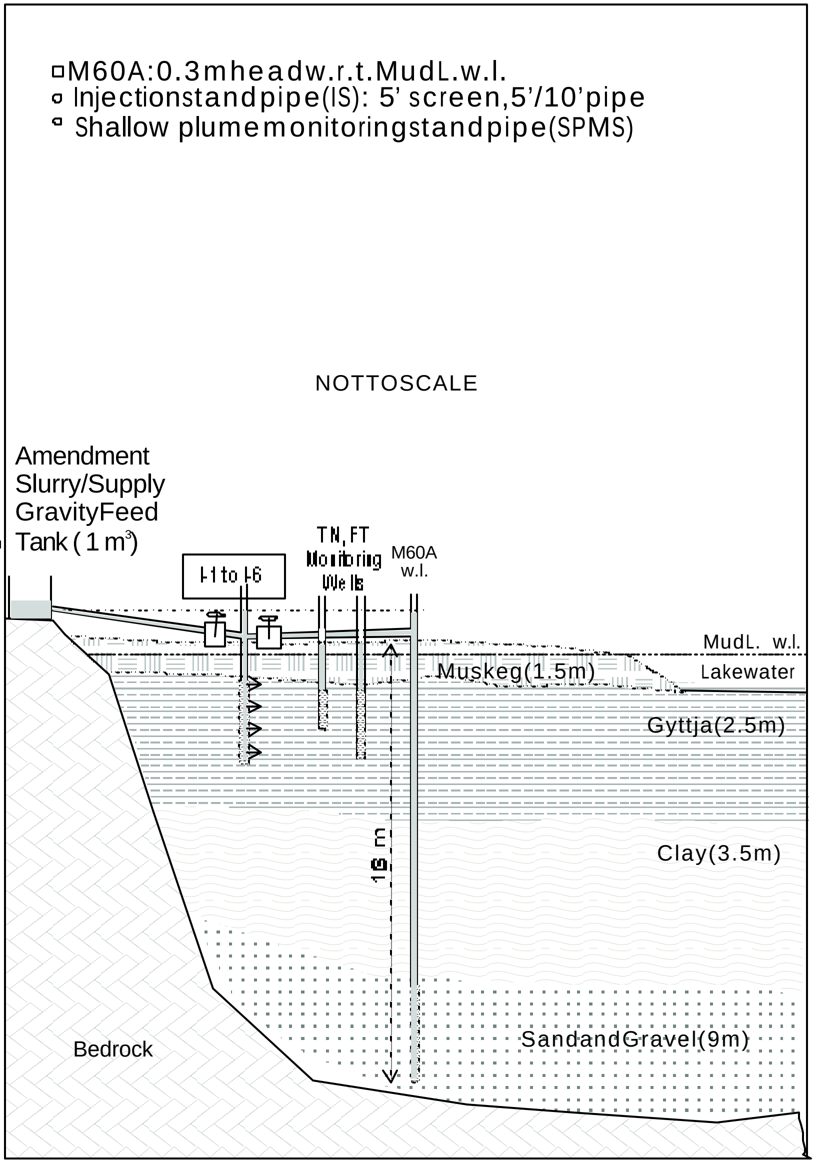

Schematic5: Mud Lake Ground Water Flows

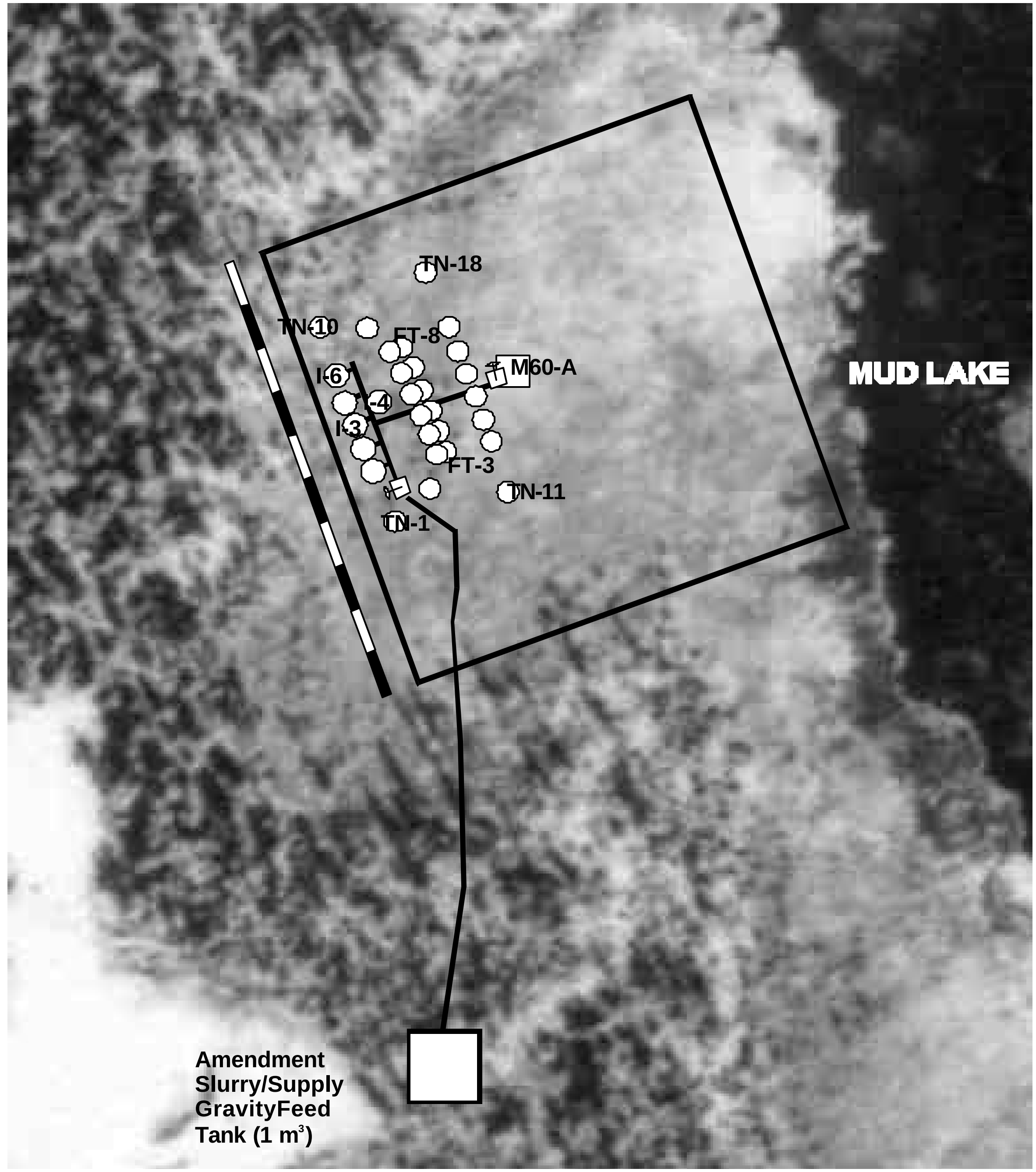



Schematic6: Effect of CumulativeBeaverDam(endof1999)(MLWL0.5mup)

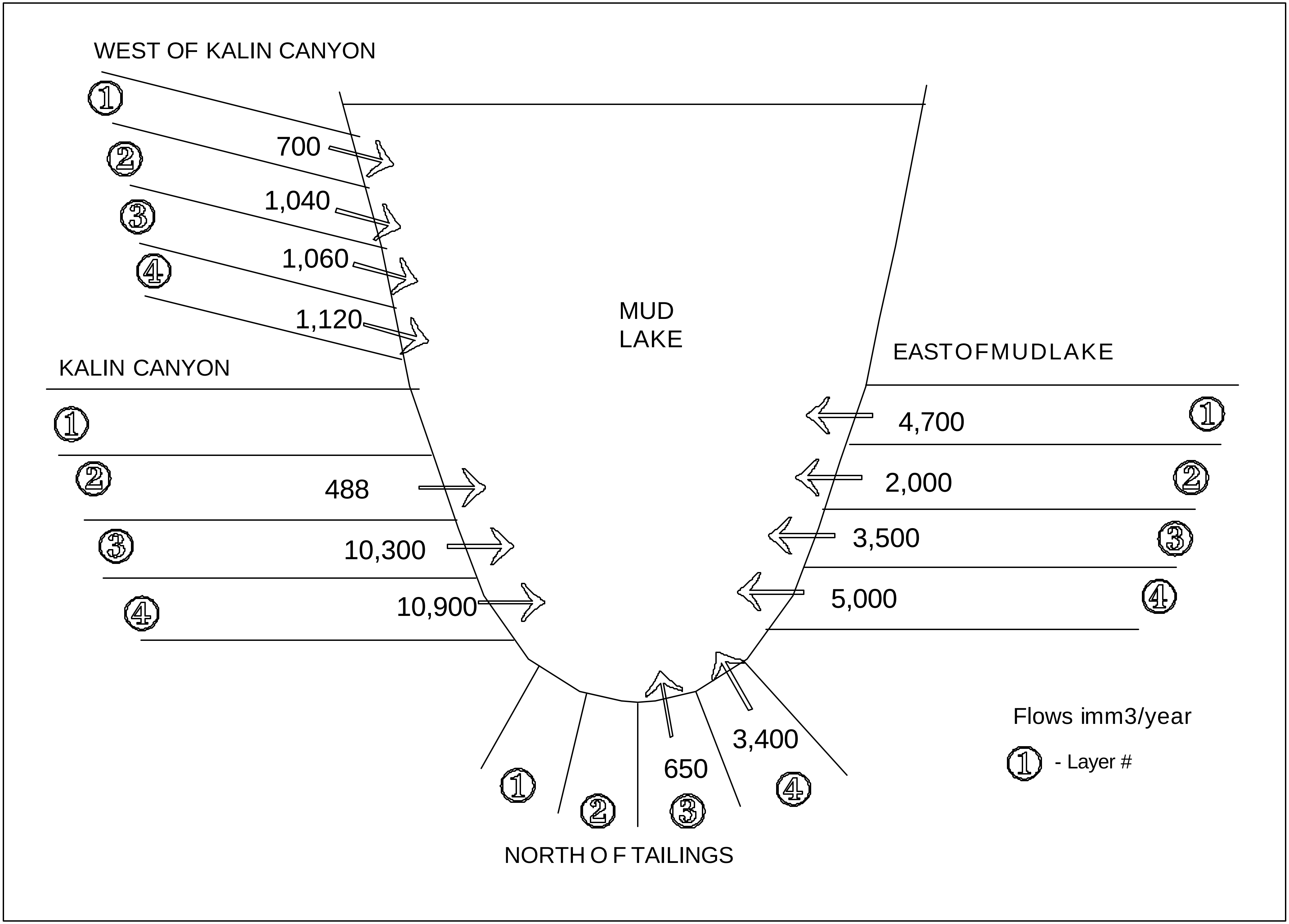



Schematic7: Effect of MaintenanceofBeaverDam (ML WL1.0mup)

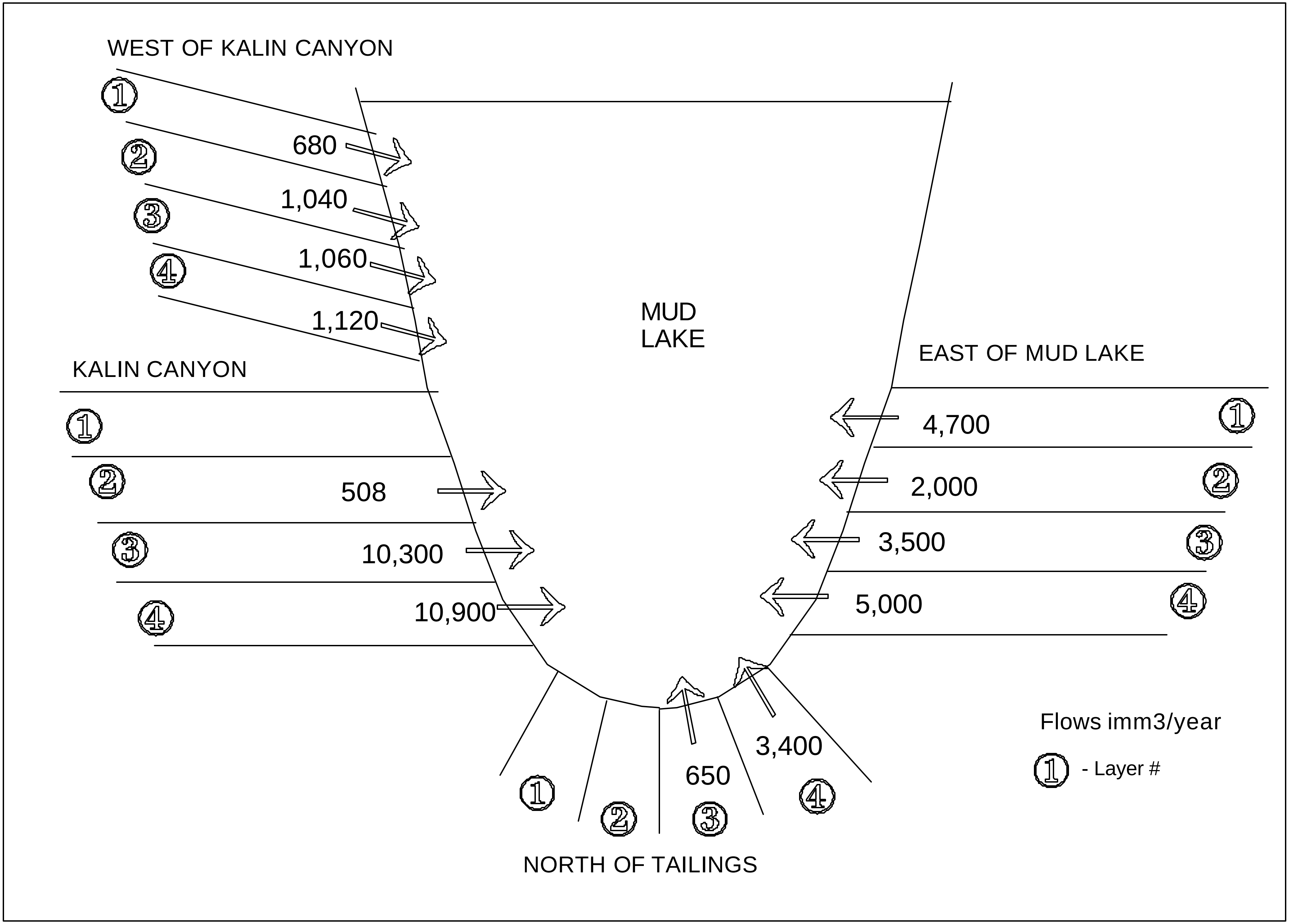



Schematic 8: Lay-out of M60A passive injection system installed in July, 2000 on region of floating muskeg adjacent to Mud Lake.




Schematic 9: Mud Lake Ground WaterFlows. Simulation of M60A Pumping (1L/sec) and Injectionbackto2Layer




Schematic10:MudLakeGroundWaterFlows.
SimulationofM60APumping (1L/sec)andInjection back to 2 Layer (splitto3injection wells)